

CHEMICAL ESSAYS.

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VOL. II.

FOURTH EDITION.

L O N D O N:

PRINTED FOR T. EVANS,

PATERNOSTER-ROW.

MDCCLXXXVII.

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ESSAY

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ESSAY

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ESSAY I.

OF THE COMPOSITION AND ANALYSIS OF GUNPOWDER.

GUNPOWDER is an artificial composition, consisting of *salt-petre*, *sulphur*, and *charcoal*. The principal things to be respected in the making of gunpowder are,—the goodness of the ingredients;—the manner of mixing them;—the proportion in which they are to be combined;—and the drying of the powder after it is made.

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A

Salt-

Saltpetre, in its crude state, whether it be brought from the East Indies, or made in Europe, is generally if not universally, mixed with a greater or less portion of common salt: now a small portion of common salt injures the goodness of a large quantity of gunpowder, hence it becomes necessary, in making gunpowder, to use the very finest saltpetre.—The purest sulphur, is that which is sold in the shops under the name of flowers of sulphur; but the roll sulphur, being much cheaper than the flowers of sulphur, and being also of a great degree of purity, it is the only sort which is used in the manufacturing of gunpowder.—With relation to the charcoal, it has been generally believed that the coal from soft and light woods was better adapted to

the making of gunpowder, than that from the hard and heavy ones; thus *Evelyn* says of the hazel that "it made one of the best coals used for gunpowder, being very fine and light, till they found alder to be more fit*."

And in another place he thinks that lime-tree coal is still better than that from alder†. An eminent French chemist has shewn, from actual experiment, that this opinion in favour of coal from light woods is ill founded; he affirms, that powder made from lime-tree coal, or even from the coal of the pith of elder tree, is in no respect preferable to that made from the coal of the hardest woods, such as guaiacum and oak.

* *Evelyn's Silva*, by Dr. Hunter, p. 223.

† *Id.* p. 946.

oak†. This remark, if it be confirmed by future experience, may be of use to the makers of gunpowder; as it is not always an easy matter for them to procure a sufficient quantity of the coal of soft wood.

The mixture of the materials of which gunpowder is made, should be as intimate and as uniform as possible; for, in whatever manner the explosion may be accounted for, it is certain that the three ingredients are necessary to produce it. Saltpetre and sulphur mixed together give no explosion; sulphur and charcoal give no explosion; and though saltpetre and charcoal, when intimately mixed, do give an explosion, yet it is, probably, of far less force than what is produced from a mixture

† Chym. par M. Baumé. Vol. I. p. 455.

ture of the three ingredients. I have said, *probably*; because this point does not seem to be quite settled at present, as may appear from the following opinions, of two eminent chemists, each of whom appeals to experience. — “ Un mélange de six onces de nitre et d’une once de charbon produit une poudre qui a *moitié moins* de force que toutes celles dans lesquelles on fait entrer du soufre : cette substance est donc absolument essentielle à la composition de la poudre. Dans le temps que je travaillois sur cette matière, quelques particuliers proposèrent de faire de la poudre sans soufre : ils promettoient qu’elle seroit plus forte, — La poudre dans laquelle on fait entrer une petite quantité de soufre,

augmente de force *du double*"*.—

" The principal ingredients of gunpowder, and those to which it owes its force, are nitre and charcoal ; for these two ingredients well mixed together, constitute gunpowder at least *equal*, if not *superior in strength* to common gunpowder (as I found by experience), and may be seen in the Memoire of Count Saluce inserted in the *Melanges de Philosophie et de Mathematiques, de l'Academie Royale de Turin*. The sulphur seems to serve only for the purpose of setting fire to the mass with a less degree of heat"†.—If I may trust some crude experiments which I have made with

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* Chy. par M. Baumé. Vol. I. p. 461.

† Philos. Transf. 1779. p. 397, where the reader will find several ingenious experiments relative to the nature of gunpowder by Dr. Ingenhousz.

a common powder Trier, I must accede to the opinion of M. Baumé; as I repeatedly found that equal *bulks* of common powder, and of the same sort of powder, freed from its sulphur by a gentle evaporation, differed very much both in the loudness and force of the explosion; the powder which had lost its sulphur being inferior to the other in both particulars. It is not without reason, that equal *bulks* are here specified, for any definite measure of common powder weighs more than the same measure of powder which has lost its sulphur; hence the result of experiments made with equal *weights* of these powders, will be different from that which is derived from the explosion of equal *bulks*: may not this observation tend to reconcile the

opinions before mentioned? But whether sulphur be an absolutely necessary ingredient in the composition of good gunpowder or not, it is certain that an accurate mixture of the ingredients is essentially requisite. In order to accomplish this accurate mixture, the ingredients are previously reduced into coarse powders, and afterwards ground and pounded together, till the powder becomes exceeding fine; and when that is done the gunpowder is made. But as gunpowder, in the state of an impalpable dust, would be inconvenient in its use, it has been customary to reduce it into grains, by forcing it, when moistened with water, through sieves of various sizes.

The necessity of a complete mixture of the materials, in order to
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have good gunpowder, is sensibly felt, in the use of such as has been dried after having been accidentally wetted. There may be the same weight of the powder after it has been dried, that there was before it was wetted; but its strength is greatly diminished on account of the mixture of the ingredients being less perfect. This diminution of strength proceeds from the water having dissolved a portion of the saltpetre (the other two ingredients not being soluble in water); for upon drying the powder, the dissolved saltpetre will be crystallized in particles much larger than those were, which entered into the composition of the gunpowder, and thus the mixture will be less intimate and uniform, than it was before the wetting. This wetting

ting of gunpowder, is often occasioned by the mere moisture of the atmosphere. Great complaints were made concerning the badness of the gunpowder used by the English in their engagement with the French fleet off Grenada, in July, 1779; the French having done much damage to the masts and rigging of the English, when the English shot would not *reach* them. When this matter was inquired into by the House of Commons, it appeared that the powder had been injured by the moisture of the atmosphere; it had concreted into large lumps, in the middle of which the saltpetre was visible to the naked eye. If the wetting has been considerable, the powder is rendered wholly unfit for use; but if no foreign substance has been mixed with it

it except fresh water, it may be made into good gunpowder again, by being properly pounded and granulated. If the wetting has been occasioned by salt water, and that to any considerable degree, the sea salt, upon drying the powder, will remain mixed with it, and may so far vitiate its quality, that it can never be used again in the form of gunpowder. However, as, by solution in water and subsequent crystallization, the most valuable part of the gunpowder, namely, the saltpetre, may be extracted, and in its original purity, even from powder that has been wetted by sea water, or otherwise spoiled, the saving a damaged powder, is a matter of national œconomy, and deservedly attended to in the Laboratory at Woolwich.

The

The proportions in which the ingredients of gunpowder are combined together, are not the same in different nations, nor in different works of the same nation, even for powder destined to the same use. It is difficult to obtain from the makers of gunpowder, any information upon this subject; their backwardness in this particular, arises not so much from any of them fancying themselves possessed of the best possible proportion, as from an affectation of mystery, common to most manufacturers, and an apprehension of discovering to the world, that they do not use so much saltpetre as they ought to do, or as their competitors in trade really do use. Saltpetre is not only a much dearer commodity than either sulphur or charcoal, but
it

it enters also in a much greater proportion into the composition of gunpowder, then both these materials taken together; hence, there is a great temptation to lessen the quantity of the saltpetre, and to augment that of the other ingredients; and the fraud is not easily detected, since gunpowder, which will explode readily and loudly, may be made with very different quantities of saltpetre.

Baptista Porta died in the year 1515; he gives three different proportions for the making of gunpowder, according as it was required to be of different strength*. I have reduced his proportions, so that the reader may see the quantities of the several ingredients, contained in 100 pounds

* Mag. Nat. L. XII. c. 3.

pounds weight of each sort of powder.

	Weak.	Strong.	Strongest.
Saltpetre	$66\frac{2}{3}$ lb.	75	80
Sulphur	$16\frac{2}{3}$	$12\frac{1}{2}$	10
Charcoal	$16\frac{2}{3}$	$12\frac{1}{2}$	10
	<hr/> 100 <hr/>	<hr/> 100 <hr/>	<hr/> 100 <hr/>

It is somewhat remarkable, that, in all these proportions, the sulphur and charcoal are used in equal quantities. *Cardan* died about sixty years after *Baptista Porta*, and in that interval, the proportions of the ingredients of gunpowder seem to have undergone a great change. *Cardan's* proportions for great, middle-sized, and small guns, are expressed in the following table.*

Salt-

* *Card. Oper. Vol. III. p. 379.*

	Gt. Guns.	Mid. sized.	Small.
Saltpetre	50lb.	66 $\frac{2}{3}$	83 $\frac{1}{3}$
Sulphur	16 $\frac{2}{3}$	13 $\frac{1}{3}$	8 $\frac{1}{3}$
Charcoal	33 $\frac{1}{3}$	20	8 $\frac{1}{3}$
	<hr/> 100 <hr/>	<hr/> 100 <hr/>	<hr/> 100 <hr/>

For great and middle-sized guns, we see a much greater proportion of charcoal than of sulphur, was used in Cardan's time; at present, I believe, it is in most places the reverse, or at least, the charcoal nowhere exceeds the sulphur. I have put down the proportions used at present in England, France, Sweden, Poland, and Italy, for the best kind of gunpowder.

Salt-

	Eng.	Fran.	Swed.	Pol.	Italy.
Saltpetre	75	75	75	80	$76\frac{1}{2}$
Sulphur	15	$9\frac{1}{2}$	16	12	$12\frac{1}{2}$
Charcoal	10	$15\frac{1}{2}$	9	8	$12\frac{1}{2}$
	<hr/> 100* <hr/>	<hr/> 100 <hr/>	<hr/> 100‡ <hr/>	<hr/> 100‡ <hr/>	<hr/> 101½† <hr/>

Several experiments have been lately made in France, in order to determine the exact proportions of the several ingredients which would produce the strongest possible powder; these proportions when reduced, as all the rest have been, to the quantity

* These are said to be the proportions of government powder.—Pemb. Chem. p. 207

|| Chem. Dict. & Baumé's Chem. Vol. I. p. 466.

‡ Mem. de Chem. Vol. II. p. 425, where it is said, that two specimens of powder from Holland, gave only 71 lb. of saltpetre from 100 of powder.

† Comm. Scien. Bonon. Vol. IV. p. 113.

tity composing one hundred pounds of gunpowder, are

Saltpetre	80 lb.
Charcoal	15
Sulphur	5
	<hr/>
	100
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From hence it would appear, that in a certain weight of saltpetre, the powder would produce the greatest effect, when the weight of the charcoal was to that of the sulphur, as 3 to 1. On the other hand, experiments are produced from which it is to be concluded, that in a certain weight of saltpetre the best powder is made, when the sulphur is to the charcoal, in the proportion of 2 to 1. From these different accounts, it seems as if the problem of deter-

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mining the very best possible proportion was not yet solved.

In drying gun-powder, after it is reduced into grains, there are two things to be avoided, too much and too little heat. If the heat is too great, a portion of the sulphur will be driven off, and thus the proportion of the ingredients being changed, the goodness of the powder, so far as it depends on that proportion, will be injured. In order to see what quantity of sulphur might be separated from gunpowder, by a degree of heat not sufficient to explode it, I took 24 grains of the powder marked FF in the shops, and placing it on a piece of polished copper, I heated the copper by holding it over the flame of a candle; the gunpowder soon sent forth a strong sulphureous vapour;

vapour; and when it had been dried so long that no more fume or smell could be distinguished, the remainder weighed 19 grains, the loss amounting to 5 grains. The remainder did not explode by a spark like gunpowder, but like a mixture of saltpetre and charcoal, and it really was nothing else, all the sulphur having been dissipated. Gunpowder was formerly dried by being exposed to the heat of the sun, and this method is still in use in France, and in some other countries; afterwards a way was invented of exposing it to a heat equal to that of boiling water; at present it is most generally in England dried in stoves heated by great iron pots; with any tolerable caution no danger of explosion need be apprehended from this method. All

the watery parts of the gunpowder may be evaporated by a degree of heat greatly less than that in which gunpowder explodes, that degree having been ascertained, by some late experiments, to be about the 600th degree on Fahrenheit's scale, in which the heat of boiling water is fixed at 212. There is more danger of evaporating a portion of the sulphur, in this way of drying gunpowder, than when it is dried by exposure to the sun.

The necessity of freeing gunpowder from all its moisture, is obvious from the following experiment, which was made some years ago before the Royal Society. A quantity of gunpowder was taken out of a barrel, and dried with a heat equal to that in which water boils ; a piece of ordnance

nance was charged with a certain weight of this dried powder, and the distance to which it threw a ball was marked. The same piece was charged with an equal weight of the same kind of powder, taken out of the same barrel, but not dried, and it threw an equal ball only to one half the distance. This effect of moisture is so sensible, that some officers have affirmed, that they have seen barrels of gunpowder which was good in the morning, but which became (by attracting, probably, the humidity of the air) good for nothing in the evening*. In order to keep the powder dry, by preventing the access of the

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air,

* — qu' il avoit vu, dans les guerres d' Italie, quelques barrells de poudre qui étoit bonne le matin, et qui ne valoit rien le soir. Hist. Nat. de l' Espagne, p. 82.

air, it has been proposed to line the barrels with tin foil, or with thin sheets of lead, after the manner in which tea-boxes are lined†.—Would it not be possible to preserve powder free from moisture, and from the loss of a part of its sulphur in hot climates, by keeping it in glazed earthen bottles, or in bottles made of copper or tin, well corked ?

This disposition to attract the humidity of the air, is different in different sorts of powder, it is the least in that which is made from the purest saltpetre; pure saltpetre, which has been dried as gunpowder is dried, does not become heavier by exposure to the atmosphere; at least, its increase of weight is very small, not amounting, as far as my experiments have

† Hist. Nat. de l'Espag.

have informed me, to above one 72d part of its weight; I rather think that it does not acquire any increase of weight. But saltpetre mixed with sea salt, attracts the humidity very sensibly, and hence, though there should be the same weight of saline matter in a certain weight of gunpowder, yet the goodness of the powder may be very variable, not only from the foreign saline matter, be it sea salt, or any other salt, injuring the quality of the powder as being an improper ingredient, but from its rendering the powder more liable to become humid.

Saltpetre being the ingredient, in which there is the greatest room for fraud, in the composition of gunpowder, and on the quantity of which its strength chiefly depends, the rea-

der will excuse the minuteness of the following process, to ascertain the quantity of saltpetre contained in any specimen of gunpowder.

Take any quantity of gunpowder, pound it in a glass mortar till all the grains are broken, lay it before a gentle fire till it be quite dry, in that state weigh accurately any quantity of it, suppose 4 ounces; boil these four ounces in about a quart of water, the boiling need neither be violent nor long continued, for the water will readily dissolve all the saltpetre, or other saline matter, and not a particle of either the sulphur or the charcoal of the powder. In order to separate the water containing the saltpetre, from the sulphur and charcoal, pour the whole into a filter made of brown paper; the water con-

containing the saltpetre will run through the paper, and must be carefully preserved; the charcoal and sulphur will remain upon the paper. But as some particles of saltpetre will stick both to the filtering paper and to the mass of sulphur and charcoal, these are to be repeatedly washed, by pouring hot water upon them, till the water in running through the filter is quite insipid; then we may be certain, that we have all the saltpetre originally contained in the powder, now dissolved in the water, and all the sulphur and charcoal remaining a mixed mass upon the filter. These respective quantities may be ascertained without much difficulty. The water containing the dissolved saltpetre, must be evaporated by a gentle heat; the saltpetre cannot be
eva-

evaporated by the same degree of heat which evaporates the water, all the saltpetre then contained in the gunpowder, will remain after the water is dispersed, and being carefully collected and weighed, it will shew the quantity of saline matter contained in the powder. Dry the mass of sulphur and charcoal, by laying the filtering paper containing it before the fire; it should be made as dry as the powder was before it was dissolved in the water: in that state weigh the saltpetre and charcoal; and, when the experiment has been accurately made, the weight of the saltpetre added to that of the mixture of sulphur and charcoal, will just amount to four ounces, the weight of the powder. The quantity of saline matter contained in any specimen of
gun-

gunpowder, being thus ascertained, its quality may be known by dissolving it in water, and crystallizing it; if any part of it crystallizes in little cubes, it is a sign that it contains sea salt; or if any part of it, after being duly evaporated, will not crystallize, it is a sign that it contains another sort of impurity, called by saltpetre makers, the *mother of nitre*, which powerfully attracts the humidity of the air.

The gunpowder marked FF, was analysed in the following manner. Twenty-four grains, by evaporating the sulphur, were reduced to nineteen; these nineteen grains gave, by solution in water and subsequent filtration and crystallization, sixteen grains of saltpetre, the charcoal, when properly dried, weighed three grains.

According to these proportions, 100 pounds of this kind of gunpowder consisted of

Saltpetre	$66\frac{2}{3}$
Sulphur	$20\frac{5}{6}$
Charcoal	$12\frac{1}{2}$

100 lb.

I tried this gunpowder in two or three other ways, by taking larger quantities of it, but the quantity of saltpetre was always 66 lb. together with some fractional part of a pound, from 100 lb. of gunpowder. The powders marked with a single and a double F, differ in the size of the grain, but they do not seem to differ, as far as I have tried them, in the quantity of the saltpetre they contain. From some sorts of powder, I have got after the rate of 76 lb. of saltpetre, from 100 lb. of the gunpowder.

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The method of analysing gun-powder, by evaporating the sulphur, is not wholly to be relied upon; I have often observed, that when mixtures of sulphur and charcoal have been exposed to evaporation, on a plate of heated copper, the remainder has weighed less than the charcoal which entered the composition, part of it having been carried off by the violent evaporation of the sulphur: and hence the proportion of sulphur in the above analysis is probably too great. I am aware that this observation is wholly opposite to the conclusion of M. Baumé, who contends, that one twenty-fourth part of the weight of the sulphur employed in any mixture of sulphur and charcoal, adheres so strongly to the charcoal, that it cannot be separated from
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it without burning the charcoal.— I can only say, that he separated the sulphur by burning it, and I separated mine by subliming it without suffering it to take fire, and this difference in the manner of making the experiment, may, perhaps, be sufficient to account for the different results.—But it is unnecessary to pursue this subject further, there are several things to be attended to in forming a complete analysis of gunpowder, which any person tolerably well versed in chemistry, would certainly take notice of, if the analysis of any particular powder was required to be made, and which cannot in this general view be minutely described: and, indeed, it is the less necessary to enter into a detail on this subject, as the strength of the powder

powder is not much affected by small variations in the quantities of the sulphur and charcoal, which enter into its composition; and the method of ascertaining the quantity and quality of the saltpetre, in any particular gunpowder, has been sufficiently explained.

In order to judge with more certainty concerning the effect of sea salt, when mixed with saltpetre, in attracting the humidity of the air, I made the following experiment. Five parts of pure saltpetre in powder, were exposed for a month to a moist atmosphere, but I did not observe that the saltpetre had gained the least increase of weight; for the same length of time, and in the same place, I exposed four parts of saltpetre
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mixed with one of common salt, and this mixture had attracted so much moisture, that it was in a state of fluidity.

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OF COMMON SALT.

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COMMON salt is a neutral salt,
it has neither an acid nor an
alkaline taste, nor does it change the
blue colour of vegetables into a red
as acids do, nor into a green as al-
kalies do. It consists of two things,
of an *acid* peculiar to itself, and of
the alkali which is separable from
the ashes of marsh samphire and
other maritime plants, and which

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has

has been denominated the *mineral* or *fossile fixed alkali*. The fossile alkali, as was observed of the vegetable alkali, when the manner of decomposing saltpetre was explained, is more powerfully attracted by the acid of vitriol than by the acid of common salt; hence common salt is effectually decomposed when it is distilled in conjunction with the acid of vitriol, for this acid expels the acid of common salt from its union with the mineral alkali, and unites itself with it in its stead: the acid of common salt being thus disengaged from its basis, is easily, by the heat, raised in vapour, and forced into the receiver. The acid of common salt, thus obtained, is very volatile, constantly emitting white fumes; and it is usually called the *marine acid*,

the *muriatic acid*, *Glauber's fuming acid* or *spirit of salt*. If the reader pours a few drops of very strong acid of vitriol on a small portion of dry common salt, he will see a white vapour arising from the salt; this vapour is the most volatile part of the acid of the salt, and a judgment may be formed of its pungency and volatility, from its presently infecting the air with its smell to a great extent. This acid vapour is a kind of air, for it retains its elasticity for some time, not being readily condensable by cold. It has engaged the attention of Dr. Priestley; and with his accustomed ingenuity, he has made several experiments, from which we learn, that this vapour when condensed, constitutes an acid which is twice as heavy as rain water, and that

the strongest acid of salt may be considered as consisting of one third of this elastic vapour, and of two thirds of water*. After the extraction of the *acid*, which is one of the constituent parts of common salt, there remains, in the vessel used for the distillation, a compound mass, consisting of the *acid of vitriol* united with the *mineral fixed alkali*, the other constituent part of common salt: this is proved by dissolving the mass, and crystallizing it, for the crystals are precisely the same as would result from a direct combination of the acid of vitriol with the mineral fixed alkali. The salt resulting from a decomposition of common salt by means of the acid of vitriol, or from a direct combination of that acid with

* Philos. Transf. 1772. p. 239.

with the mineral alkali, is the *genuine Glauber's salt*. The artificial composition of common salt, confirms the account we have given of its constituent parts from its analysis, for if we combine the acid procured from distilling common salt and acid of vitriol together, with the mineral fixed alkali, there will result from their union, a salt, in all respects the same as common salt, except that it will be somewhat more pure than common salt; the salt thus produced is called *regenerated salt*.

Common salt is generally distinguished by mineralogical writers into three different sorts—*fossile salt*—*spring salt*—*sea salt*. In chemistry though we admit this division, as serviceable in pointing out the three general sources from which common

salt is most copiously derived, yet we reckon all these salts, when pure, to be of the same sort; they are all composed of the *marine acid*, and of the *mineral fixed alkali*.

Fossile or *rock salt*, is found in large beds in the bowels of the earth, in every quarter of the globe; it is sometimes crystallized, and as transparent as a diamond, and it has thence been called *sal gemmæ*; but it is more frequently found in irregular masses of a red, yellow, or blue colour. There are several mines of rock salt near *Northwich* in *Cheeshire*; the first of which was discovered, as they were boring for coal, in the year 1670*.

The springs which are met with, both *above* and *below* the level of the *Northwich* bed of rock salt, are strongly

* *Philos. Transf. No. 66.*

strongly impregnated with salt. This is easily accounted for; the rain water in sinking through the ground which lies over the rock salt, at last arrives at the salt; its further descent is in a great measure obstructed by the solid body of salt, it rests upon it, and in resting upon the salt it dissolves it, and thus constitutes a brine spring above the level of the bed of rock salt. The brine springs, which are found below that level, probably arise from the water, which has dissolved a portion of rock salt, in sinking to that depth in the earth.

I have had the curiosity to go to the bottom of some of the most famous mines in England; such as the copper mine at Ecton; the coal mines at Whitehaven and Newcastle; the cannel coal mines in Lancashire; and

a variety of lead mines in Derbyshire, and other places; but I never thought my labour, in these subterraneous expeditions so well rewarded, as in the sight of the rock-salt mines at Northwich. The salt mines at *Wilzka* near *Cracow* in Poland, have long been a subject of admiration, and every traveller has exerted his descriptive talents, in magnifying the stupendous wonders which are there to be met with. These mines have been wrought above five hundred years, and from that circumstance we may readily imagine, the great number of vast caverns which have been formed in consequence of the blocks of salt which have been annually extracted: yet it deserves to be remarked, that the Northwich rock salt mines are superior to those

of Cracow, with respect to the quantity of salt which is annually raised. The single pit into which I descended at Northwich, yielded at a medium 4000 tons of salt in a year; this quantity is about two thirds of that which is raised every year in the Polish mines here spoken of.*

A great quantity of rock salt is used at Northwich, in order to strengthen their brine springs, and a much greater quantity is sent coast-ways to Liverpool and other places, where it is used either for strengthening brine springs or sea water; much of this rock salt was formerly exported to Holland, and it is still sent to Ireland for the same purpose. Rock salt, and the white salt which
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* See Memoire sur les Mines de Sel de Wieliczka en Pologne, in Hist. de l'Acad. des Scien. a Par. 1762.

is at Northwich, chiefly made from rock salt, is exported free from the salt duty; and I was informed that the quantity which is annually exported from Northwich, is so great, that, if it paid the duty, it would bring in to government, a sum not much short of four hundred thousand pounds a year. "According to the best accounts I have been able to procure, the gross duty on salt made in South Britain, amounts annually to seven hundred thousand pounds.*" The duty on salt made at Northwich is about seventy thousand pounds a year, or a tenth part of the whole duty†.

The

* Camp. Sur. of Brit. Vol. II. p. 26.

† Since I received this information, an additional duty of 1cd. a bushel has been laid, in 1780, on salt. The whole duty now amounts
to

The Northwich rock salt is never used at our tables in its crude state; and its application to the pickling or curing of flesh or fish, or preserving any provisions, without its being previously refined into white salt, that is, without its being dissolved in water, and boiled down into what is called white salt, is prohibited under a penalty of 40s. for every pound of rock salt so applied. The pure transparent masses, however, of rock salt, might, probably, be used by us with our food, without any sort of danger or inconvenience; at least, we know that rock salt is so used, without being refined, both in *Poland* and in *Spain*. In the last of these countries,

at

to 4s. 2d. the bushel, the bushel weighing 56lb. The makers of salt can afford, in most places, to sell their salt, exclusive of duty, from 8d. to 10d. a bushel.

at *Cordona* in the province of *Catalonia*, there is a solid mountain of rock salt, between four and five hundred feet in height, and a league in circuit; its depth below the surface of the earth is not known*. This prodigious mountain of salt, which has no mixture of other matter with it, is esteemed so singular an appearance, that it is thought to militate very much against the opinion of those, who would derive the origin of all the beds of rock salt, which are found under the surface of the earth, from the evaporation of salt water, left in subterraneous caverns, either at the deluge, or upon some more local commotions of the globe.

The

* Hist. Nat. de l'Espag. p. 406. See an account of similar mountains of rock salt in Shaw's Travels, p. 229, and in Pliny's Hist. Nat. l. xxxi. c. 7.

The quantity of rock salt which may be dissolved in a definite quantity, suppose a pint or 16 avoirdupois ounces of water, is differently estimated by different authors. *Boerhaave* is of opinion, that 16 ounces of water will not dissolve quite five ounces of rock salt*; *Spielmann* thinks that they will dissolve $6\frac{2}{3}$ ounces†; *Newmann* agrees with *Spielmann*‡; *Eller* says, that seven ounces of fossile salt may be dissolved in 16 ounces of water§; lastly, *Hoffmann* assures us, that 16 ounces of water will not dissolve above six ounces of common salt||. I have tried this matter with distilled and with common water, and

* Chem. Vol. I. p. 476.

† Inst. Chem. p. 48.

‡ Newmann's Chem. by Lewis, p. 256.

§ Obs. Phy. Chem. L. ii. Ob. xvi.

|| Ber. Mem. 1750.

and in various degrees of heat, and cannot but be of opinion, that Hoffmann's experiment approaches nearest to the truth; I never could dissolve *quite* six ounces of rock salt in 16 ounces of water. It is not wholly improbable, that different sorts of rock salt, may differ somewhat with respect to their solubility in water.

If it be admitted, that 16 ounces of water can dissolve six ounces of salt and no more, then we may be certain, that no brine spring, in any part of the world, can yield six ounces of salt from a pint of the brine. For brine springs are, ordinarily, nothing but water in which fossile salt has been dissolved; but a pint of the strongest brine cannot contain so much salt, as is contained in a pint of water, which has been saturated with

with six ounces of salt ; for a pint of water, in which six ounces of salt have been dissolved, is increased a little in bulk, it will do more than fill a pint measure, and the salt left in the surplus will shew, how much the salt, contained in a pint of the strongest brine, falls short of six ounces. Or we may consider the matter in the following manner, which will, perhaps, be more intelligible ; 16 ounces of water, impregnated with six ounces of salt, constitute a saturated brine, weighing 22 ounces ; if therefore we would know how much salt is contained in 16 ounces of such brine, by the rule of proportion we may argue, that if 22 ounces of brine contain six ounces of salt, 16 ounces of brine will contain $4\frac{4}{11}$ ounces of salt. Hence we may infer, that the
strongest

strongest brine springs will not yield much above one quarter of their weight of salt*.

Dr. Leigh, who first shewed the manner of refining rock salt, informs us, that some of the strongest springs at Northwich, gave seven or eight ounces of salt from a quart of brine; but a quart of brine weighs considerably more than 32 ounces, the weight of a quart of water; so that the Northwich springs, from this account,

* ——— “ Several pits at *Northwich*, and at *Barton* in *Lancashire*, contain no less than six ounces of salt upon sixteen of brine; which is as large a proportion of salt as water will dissolve.” Newm. Chem. p. 212, Lewis’s note. The author here is fallen, probably, into a little mistake, by confounding a pound of water with a pound of brine; for if a pound or 16 ounces of water will only dissolve six ounces of salt, a pound of the brine, thus formed, will only hold $4\frac{4}{11}$ ounces of salt.

count, do not yield a quarter of their weight. At *Middlewich* there is said to be one salt spring, which is stronger than the rest; this spring yields a *full fourth* part of salt*, and hence it is, probably, fully saturated. We have an account in Kircher's works, of some famous brine springs in *Burgundy*, from which we learn, that one hundred pounds weight of the strongest brine, gave 25 pounds, or just one *fourth* of its weight of white salt †.

There are a great many brine springs in *Cheshire*, *Worcestershire*, *Staffordshire*, *Hampshire*, and in other parts of Great Britain, some of which are sufficiently rich in salt to be wrought with profit, others not.

From

* *Philos. Transf.* No. 53.

† *Kirch. Mun. Sub. Tom. II. Cap. XI.*

From what has been before advanced the reader will readily comprehend that 16 tons of the strongest brine consist of 12 tons of water, and of 4 tons of salt; and that, in order to obtain these 4 tons of salt, the 12 tons of water must be, by some means or other, evaporated, so as to leave the salt in a concrete form. Suppose there should be a brine, which in 16 tons, should contain 15 tons of water, and only 1 ton of salt; yet it may chance, that such a weak brine may be wrought with more profit than the strongest; for the profit arising from the boiling of brine into salt, depends as much upon the price of the fuel used in boiling it, as upon the quantity of salt which it yields. Thus the sea water, which surrounds the coasts of Great Britain, is said to hold

hold seldom more than one thirtieth, or less than one fiftieth part of common salt; but fuel is so cheap at Newcastle, that they can evaporate thirty or forty tons of water, in order to obtain one ton of salt, and yet gain as much clear profit as those do, who, in counties less favourably situated for fuel, boil down the strongest brine.

The advantage resulting from strengthening weak brine or sea water, by means of rock salt, is very obvious. Suppose that the sea water at Liverpool, where large quantities of rock salt are refined, would yield 1 ton of salt from 48 tons of water, then must a quantity of fuel sufficient to evaporate 47 tons of water be used in order to obtain 1 ton of salt. But if as much rock salt be

put into the 48 tons of sea water, as can be dissolved in it, then will the sea water resemble a brine fully saturated, each 16 tons of which will give 4 tons of salt, and the whole quantity yielded by the evaporation of 47 tons of water, will be 12 tons of salt.

In warm climates, such as *Italy*, *Spain*, and the southern provinces of *France*, where the heat of their summer is sufficient to exhale considerable depths of water in a little time; they prepare large quantities of what is called *bay salt*, at a very small expence. Their general method is to select a marshy spot of ground, communicating by sluices with the sea, and sufficiently removed from fresh springs, and the mouths of large rivers. In this ground they form
usually

usually three pits of small but different depths, and by clay and timber they secure them from leaking. The sea water is let into the first and deepest pit, from which it flows slowly, so as to give the mud and sand time to settle, through the second into the third, where it is soon inspissated by the heat of the sun into a strong brine. This brine being still further evaporated by the continued action of the sun, concretes into crystals of salt, which gradually sink to the bottom of the pit. When a proper quantity of it is formed, it is drawn out for use, and is of different colours, according to the colour of the clay employed in making the pits. In a favourable season, the French are said to be able to make enough of bay salt in a fortnight, to

supply their home consumption for a year, and the wants of the other nations, who purchase from them much more than is consumed in France*.

In this method of making bay salt, art has but copied nature; for we read in Pliny, Alonso Barba, Shaw, and others, of large briny lakes, which are evaporated, in many parts of the world, to a perfect dryness in summer time; when the inhabitants cut and carry away as much salt as they have occasion for. A remarkable lake of this kind was met with by Mr. Maffon, in his botanical excursions from the Cape of *Good Hope*. “ *Zwart Kop’s* salt-pan, is a lake several

* See Dr. Brownrigg’s Treatise on the Art of making common Salt, where the reader’s curiosity on this subject will be abundantly gratified.

veral miles distant from the sea, and upon an eminence. In the rainy season it is filled with fresh water, which by the saltness of the ground, soon becomes strongly impregnated with saline particles; and when the summer's heat exhales the fresh water, the bottom of the lake is covered with a crust of pure salt, two or three feet thick. The lake is about three miles round, and surrounded by a rising ground*."

Though it appears, from what Dr. *Brownrigg* has said upon this subject, that we might, with much advantage to our trade, imitate the French in their manner of procuring bay salt; yet most of our salt is prepared by boiling either the brine of salt springs, or sea water, into white

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salt.

* *Philos. Trans.* 1776. p. 297.

salt. In Hampshire, and some other counties, they have a method of heightening the sea water into a strong brine, by exposing it to the sun in large pits, much after the manner in which bay salt is made; and so much of the sea water is, by this means, naturally evaporated, that though they boil the remainder with Newcastle coal, yet they can afford their salt at a less price, than the Newcastle salt boilers can afford theirs; though the sea water is, probably, equally impregnated with salt at both places.

The greatest difficulty which attends the making of bay salt in Great Britain, arises from the heat of our summer not being sufficiently strong, to evaporate a great quantity of sea water in a small portion of time. I
will

will mention an experiment or two, which suggested a hint, that may not, perhaps, be unserviceable to those who shall, in future, be disposed to attempt the making of bay salt.

I took a piece of coarse linen cloth, its area was a square yard, and having thoroughly wetted it with water, but not so much as to cause it to drip, I weighed it, and in that wet state exposed it to a warm sun in June, when there happened to be but little wind; it was not laid upon the ground, but held opposite to the sun, so that the air and sun had a free access to every part of it; it became nearly dry in an hour, and in that space of time it had lost eight ounces of its weight. — Upon another occasion, when there was a bright sun and a brisk wind,

wind, on an April day, a similar experiment was made; and the cloth lost after the rate of 6 ounces in one quarter of an hour; hence, if it had been kept constantly wetted, it would have lost in 16 hours 24 pounds; a pound of water is equal to a pint in measure, and therefore we may infer, that in a summer day of 16 hours in length, 24 pints, or three gallons of water may be dispersed into the air, by a warm sun and a brisk wind, from the surface of a linen cloth, equal to one square yard.

Now it is very possible, in any place where bay salt is made, to devise means of wetting and drying alternately any number of square yards of coarse cloth; one labourer, assisted by proper mechanical contrivances, might be equal to the daily management

ment of a thousand yards, or more. By this plan, in favourable weather, there would be daily evaporated twenty-four thousand pounds of water, which, supposing sea water to contain one thirty-second part of its weight of salt, would give 750 pounds of salt. Those who have seen the artifice of strengthening brine, which is practised in *Franche-Comtè*, and other places, by making it drip through faggots, in order that the evaporation may be increased, by increasing the surface of the water which is exposed to the air, will not be surpris'd at the method of evaporating water here hinted at.

Though the constituent parts of common salt, when free from all heterogeneous mixtures, are probably the same in every part of the world,
yet

yet in the ordinary state in which it is met with, it is found to have very different qualities, and may properly enough be divided into different sorts. Bay salt differs in some of its properties from the white salt, prepared by boiling brine or sea water; and both the bay salt and the boiled salt have, respectively, different qualities, according as they are prepared at different places. There are two general reasons of this diversity; one respects the manner of preparing the salt, the other respects the quality of the water from which the salt is prepared. When sea water or brine is boiled into salt, a portion of the acid, which is one of the constituent parts of the salt, is dispersed; and a greater or less portion is dispersed, according as the salt has been formed
with

with a greater or less degree of heat. We have an instance of this, both in bay salt when compared with boiled salt, and in the different sorts of boiled salt, when compared with each other. Bay salt is prepared from sea water, by the mild heat of the sun, and it is generally esteemed much stronger than the white salt, which is prepared likewise from sea water by boiling the sea water. At Northwich, and in other places, they prepare from brine, not only the ordinary white salt, but a salt whose crystals are much larger than the ordinary salt, and which is usually called shivery salt. This shivery salt is esteemed stronger than the other, and it is formed by a milder heat; for in forming the ordinary salt, the brine is kept gently boiling; but in
forming

forming the large grained shivery salt, they let the brine cool till they can bear to put their hands into it, and keeping it in that state, as near as may be, from Saturday night to Monday morning, the shivery salt is gradually formed. Sea water, brine springs, and rock salt, generally contain besides common salt, various other earthy and saline ingredients, such as the *calcareous earth* from which fish shells are probably formed;—the earth called *magnesia*;—*Epsom salts*, or the salt resulting from the combination of the acid of vitriol with *magnesia*;—*Selenites*, or the salt resulting from the combination of the acid of vitriol with the earth of the nature of fish shells;—*Glauber's salt*;—*fixed alkali* uncombined with any acid, &c. Sometimes all these

heterogeneous substances, and sometimes only a few of them are found in the waters from which common salt is prepared; they are all of them foreign to the nature of the salt, and injure its quality; and hence we may, without difficulty, comprehend that common salt may have very different properties, according to the quality of the water from which it is made, or the skill of the salt-maker exerted in separating these mixtures from it. The *Dutch* have long been famous for preparing a salt for the pickling of herrings, by which they have acquired a superiority in that article of commerce over all other European nations. Their principal secret in this business consists in evaporating the brine made from the solution
of

of bay salt with the gentlest fire, and in mixing with the brine a proper quantity of very *sour whey*; the acid whey unites itself with the uncombined fixed alkali before mentioned, and thus prevents it from adhering to the common salt as it crystallizes. Any other mild acid might probably answer the same purpose. This acid whey is called *azy*: les Hollandois se servent de l'*azy* dans le travail en grand pour raffiner nos sels de mer, et pour en rendre la cristallisation parfaite; c'est par cet artifice qu'ils sont depuis long-temps, en possession de fournir les meilleures salaisons de l'Europe*.

* Hist. de l'Acad. des Scien. 1762. Dr. Brownrigg had mentioned this secret of the Dutch above 30 years ago, in his excellent treatise before referred to. The reader will meet

meet with an accurate examination of the various ingredients with which common salt, and the waters from which it is made, are impregnated in Baumé's Chem. vol. iii. p. 512.

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ESSAY III.

OF COMMON SALT AND NITRE AS MANURES.

COMMON salt, in the earliest ages of the world, was so far from being held in any estimation as a manure, that it was looked upon as a symbol of extreme sterility. Long before the commencement of profane history, *Abimelech* took the city *Shechem*, and *slew the people that was therein, and beat down the city, and sowed it with salt**; intimating thereby.

* Judges ix. 45.

by his wish that it might remain unfruitful and uninhabited for ever.

It does not appear from history, what circumstance gave rise to this custom, or whether Abimelech was the first person who introduced it; but it has prevailed very generally among mankind even to the present age, it being still usual to raze the houses of rebels and traitors, and to sprinkle the ground upon which they stood with salt. Perhaps this general symbolical use of salt, might be derived from what had happened when *Sodom* was destroyed, and the *salt sea* was formed. This conjecture is, in some measure, supported by observing, that the severest denunciations of divine vengeance are frequently expressed by an allusion to that event.—*Moab shall be as*

Sodom, and the children of Ammon as Gomorrah, even the breeding of nettles, and salt pits, and a perpetual desolation. The whole land thereof is brimstone, and salt, and burning, that it is not sown, nor any grass groweth therein, like the overthrow of Sodom†.*

Virgil reprobates a salt soil, as occasioning the degeneration of fruit trees, and admitting no melioration from ploughing.

*Salt earth and bitter are not fit to sow,
Nor will be tam'd or mended with the
plough.*

*Sweet grapes degen'rate there, and fruits
declin'd*

*From their first flav'rous taste renounce
their kind ‡.*

Pliny,

* Zephaniah, ii. 9.

† Deuteron. xxix. 23.

‡ Virgil's Georg. l. 2. Dryd.

Pliny, though he recommends the giving of salt to cattle, yet in speaking of fossile salt, he expressly affirms, that every place in which it is found, is barren and unfit for vegetation*.

Notwithstanding these and other testimonies of the ancients concerning the sterilizing quality of common salt, yet it is frequently used as a manure with great success. It has been the custom, ever since the time of Henry the Third at least, for the farmers on the *Cornish* coast, to manure their lands with sea sand, in which sea salt is so copiously mixed, that in many places it used to be extracted from a lye made of sand. When the sand has been long exposed to the air, it proves less useful
and

* Hist. Nat. L. xxxi. c. 7.

and enriching, which is by some attributed to its having been deprived of a good part of its salt, by the dews and rains*. It may be observed, that this sand is of two kinds, shelly and shelly; the shelly is produced from the grating of stones one against another, by the constant wash of the sea, and is of little value; its quality, however, will be different in different countries, according to the nature of the stones exposed to the agitation of the sea; if the stones happen to be of the limestone kind, even the shelly sand may be very serviceable; if the stones principally consist of flint, as at Yarmouth, and other parts of the Norfolk coast, the sand will differ very little from powdered flints. The shelly sand in Cornwall,

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is

* Camden's Britan. Cornw.

is produced by the same fluctuation of the sea, as the flinty sand in Norfolk; it consists of the broken shells of muscles, cockles, oysters, scollops, and other fish. This sand varies somewhat in colour and in grain, according to the substances from which it is formed, and the degree of agitation it has been exposed to, and it is found to fertilize almost all kinds of soils*. This practice of manuring lands with sea sand, has, within these few years, been introduced with great success in other parts of Great Britain.

The *Cheshire* farmers purchase no inconsiderable quantity of refuse salt from the salt boilers; they mix it with dung, and it makes an excellent manure. This refuse salt costs them
eight-

* *Philos. Trans.* No. 113.

eightpence a bushel, there being a duty of fourpence a bushel imposed on it. When the demand for this refuse salt is very great, the salt boilers have a custom to mix a quantity of soot, or other impurity, with the ordinary salt, and it then comes under the denomination of refuse salt; there were sold a few years ago, at Northwich alone, near 3000 tons of it in one year, for the use of the farmers in that and other counties. On the other hand, when the soil abounds with rushes and weeds, it is customary in Cheshire, to lay a quantity of rock salt upon it, as it is found utterly to destroy every vegetable. Hence it should seem, that salt, when used in small quantities, is a good manure, and when in large ones, a real poison to vegetables. Some of the African and
Arabian

Arabian deserts are thought to be barren by their having too much salt in them; whilst many parts of Barbary are reckoned to be peculiarly fruitful, from their containing a less quantity of it*.

Sir *John Pringle* has observed, that common salt, when used in small quantities, as one ounce to twelve, accelerates the putrefaction of animal substances, when in larger it retards it; and hence he deduces its utility, in assisting the organs of digestion in man, and, perhaps, in other carnivorous animals†. The same observation may be extended to graminivorous animals, they are all exceedingly fond of salt, probably from

* Brownrigg on Salt, p. 159.

† Observ. on the Diseases of the Army, by Sir J. Pringle, Appen. xxxix.

from its great tendency to corrupt the aliment, and to render thereby its discharge from the stomach into the intestines, more easy and expeditious.

In like manner salt, when applied as a manure, in small quantities, is found to be very beneficial; not probably from its entering as an aliment into the substance of vegetables, since there are many experiments tending to prove that no kind of salt can of itself become the food of plants*,
but

* Wallerius expressly says — *Les fels de quelle espece qu' ils soient, ne peuvent pas servir de nourriture aux plants, ni avancer par eux-memes la vegetation*; and after quoting the experiments of Kraftius, Alston, and Bonnet, on the subject, and examining the arguments on the opposite side of the question, he concludes the inquiry in the following words :

but from its efficacy in reducing weeds, dried herbage, dead roots, &c. into a putrid oily mass; the fructifying virtue of oily composts being now generally acknowledged; but when it is used in a larger proportion, by preserving these matters from corruption, and drying up or hardening the fibrous capillaries of the roots, so that they become unfit for sucking in nutriment, the fertility

words: — D’ou nous concluons que les sels minéraux, ni les sels étrangères, ni les terres minérales, ne contribuent point à la nourriture des végétaux. *Elemens d’Agriculture traduits du Latin de M. Wallerius.* Yverden, 1766, p. 134, &c. or an English translation of the same work, by John Mills, Esq. F. R. S. London, 1770. See also the *Principles of Agriculture and Vegetation*, by Dr. Home; and the *Elements of Agriculture*, by Dr. G. Fordyce.

lity of the ground is diminished, or wholly destroyed.

As to the fertility of lands overflowed by sea water, it may be in part owing to the slime and mud left by it, and partly to the salt contained in it, which, being in a small quantity, may contribute to the putrefaction of the effete vegetable roots, and the consequent production of an oily compost.

With respect to nitre as a manure, it is an opinion entertained by farmers, that snow fertilizes the lands upon which it falls, more than rain, in consequence of the nitrous salts which it is supposed to acquire by freezing. False philosophy first gave rise to this idea*, and poetry has

con-

* Gassend. *Phys.* sec. iii. l. 11. The existence

contributed to spread the general error.

— Oh! may'st thou often see
Thy furrows whiten'd by the woolly rain
Nutritious, secret *nitre* lurks within
The porous wet, quick'ning the languid
glebe.

PHILIPS.

What art thou frost? —
Is not thy potent energy, unseen
Myriads of little *salts*, or hook'd or shap'd
Like double wedges, and diffus'd immense
Thro' water, earth, and ether.

THOMPSON.

The

istence of nitre in snow, and the fertilizing quality of salts, were so generally admitted in the last century, that philosophers seem to have been at no pains to prove either of them, — On *sait* que la *neige* contient beaucoup de parties *nitreuses*, et que les *sels* contribuent beaucoup à la *fécondité* des terres. Actes de Copenhague, Collect. Acad. vol. vi. p. 195.

The ancients were acquainted with the fertilizing quality of snow, and though they did not very intelligibly explain its mode of operation in promoting vegetation, yet it is remarkable, that the supposition of saline corpuscles made no part of their illustration of that matter*. It is not here intended to deny the fertilizing virtue of snow, but to shew that it probably does not proceed from the nitre contained in it; in support of this opinion, I will mention two of the most accurate experiments, which have probably ever been made on the subject.

Marggraf, in the year 1751, collected in the suburbs of Berlin as much snow as, when melted, afforded him one hundred measures of
water,

* Plin. Hist. Nat. l. xvii. c. 2.

water, each measure containing thirty-six ounces*. He collected the snow in an open situation, in clean glass vessels, after the atmosphere was purified, by its having snowed some time; in short he used every possible precaution to procure the snow free from every extraneous impurity. The nitrous or other salts contained in the snow as it fell upon the ground were, no doubt, dissolved in the water after the snow was melted; and, in order to ascertain their quantity and quality, nothing more was requisite than to dissipate by evaporation or distillation, the water in which they were dissolved. From these hundred measures of snow water he obtained, by distilling it with every suitable attention, 60 grains,

not

* Opus. Chy. vol. ii.

not of *nitre*, but of *calcareous earth*, together with some grains, he does not mention the exact number, of the acid of sea salt, impregnated with a nitrous vapour.

The same quantity of rain water, collected in the winter months with equal precaution, and distilled with equal attention, yielded 100 grains, not of *nitre*, but of *calcareous earth*, with some grains of the acids of nitre and sea salt*.

The

* Toute la difference donc entre l'eau de pluie et l'eau de neige n'est d' aucune importance, et se réduit à ce que l'acide de l'eau de pluie est plus *nitreux*, et qu'elle renferme plus de terre calcaire, au lieu que l'eau de neige a plutôt un acide *marin que nitreux*, et contient une moindre quantité de terre calcaire. Opuscules Chymique, vol. ii. p. 21.

The author infers from these experiments, that the chemical difference between rain and snow water is exceedingly small; but that the latter, however, is somewhat less nitrous, and contains a somewhat less proportion of earth than the former. But neither of them contains either earth or any kind of salt in any quantity, which can be sensibly efficacious in promoting vegetation.

Suppose an acre of land to be, at any one time, covered with snow to the depth of six inches; and that this snow would, when melted, be reduced in magnitude a sixth part, or that it would cover the land with water to the depth of one inch; then might it be made appear, by a very easy calculation, that allowing 60 grains of calcareous earth to every

28 gal-

28 gallons and one pint of water, according to the proportion of the foregoing analysis, the whole of the earth left upon the acre from the evaporation of the snow water, would not amount to ten pounds in weight; nor the saline part to above a few ounces. Now it is very improbable that four or five ounces of any kind of salt, when spread over an acre, should produce any sensible effect in fertilizing the ground. And if we suppose the land to be so often covered with snow in the course of a year, that the salt left upon it would amount even to a pound, yet the difficulty would still recur, since even a pound of salt reduced to an uniform pellicle, and spread over an acre of land, would not much exceed in thickness, the four hundred

thousandth part of an inch. So that if it should be admitted that nitre is a fertilizer of land, which many are, upon good grounds, disposed utterly to deny, yet so very small is the quantity of it contained in snow, that it cannot be supposed to promote the vegetation of plants upon which the snow has fallen.

The peculiar agency of snow as a fertilizer, in preference to rain, may admit of a very rational explanation, without having recourse to any nitrous salts, which it has been supposed to contain. There are two causes constantly acting upon the surface of the earth, one of which is, generally speaking, uniform in its strength with respect to the production of heat; the other is variable. The internal substance of the earth

is heated uniformly, by some principle or other which we do not well understand, to the 48th degree of Fahrenheit's thermometer; this degree of heat is greater than that in which the watery juices of vegetables freeze, and it is propagated from the inward parts of the earth to the surface on which the vegetables grow. The atmosphere being variably heated, by the variable action of the sun in different climates, and in the same climate at different seasons, communicates to the surface of the earth, and to some distance below it, the degree of heat or cold which prevails in itself. Different vegetables are able to preserve life under different degrees of cold; but all of them perish, when the cold which reaches their roots is extreme. Providence,

dence, in the coldest climates, has provided a covering for the roots of vegetables, by which they are protected from the influence of the atmospheric cold; that *covering* is *snow*. Even in our climate we often see shrubs, and other small vegetables, killed by the severity of a frost, when it is unaccompanied with snow, which, had there been eight inches, or a foot of snow upon the ground, would have remained unhurt. The snow keeps in the internal heat of the earth, and it does not permit the cold of the atmosphere to penetrate through its substance, and on both these accounts it keeps the roots of the vegetables, comparatively speaking, warm; a kind of vegetation is carried on under its surface, which shews itself by the very rapid increase
which

which plants of all kinds acquire in cold countries, as soon as the covering of snow is removed by the approach of spring. Those who are fond of making oil the food of plants, may derive part of the utility of snow in fertilizing the earth from the oily particles which it contains; for not only the residue which was obtained from the distillation of snow water, had a brown colour proceeding from some oily particles, but it is very commonly observed that snow, as it thaws, becomes dirty; and this dirty appearance is probably enough referred to some particles of an oily or a mucilaginous substance contained in it. Snow, moreover, in melting, moistens and pulverizes the soil, which had been bound up

by the frost; and as its water has a tendency to putrefaction, it seems, on many accounts, without admitting it to contain any nitre, to be admirably fitted to promote vegetation.

In confirmation of the analysis of rain and snow water which were made by Marggraf, I will here add those which we owe to the accurate industry of Dr. Ruty*.—He evaporated six different specimens of the purest rain water he could procure, and found that a gallon of the purest yielded six grains, and a gallon of the most impure 12 grains of a substance, for the most part, of a dark brown colour, and a *bitter, brackish* taste. From a gallon of snow water, he obtained 4 grains of a brownish residue, which consisted partly

* Ruty's Synop.

partly of *sea salt*, partly of an absorbent earth, and a small portion of oil.

It may be observed from these experiments, compared with those of Marggraf, that the proportion between the solid impurities of rain and snow water, is much the same, in parts of the globe as far distant from each other as *Ireland* and *Prussia*. Dr. Rutty's experiments were made in Dublin; a gallon of the purest rain water gave him 6 grains, the same quantity of the purest snow water gave him 4 grains of heterogeneous matter; now the proportion of 6 to 4, is not very different from that of 100 to 60, which expresses the proportional quantities of the residues left, from the evaporation of rain and snow water,

water, according to the experiments of Marggraf.

No two authors perfectly agree in ascertaining the quantity of solid impurity contained in a definite portion of either rain or snow water; this is not to be wholly attributed to the difference of their care and skill exerted in the analysis of them, but principally to the different natures of the subjects themselves, upon which their labours have been employed. The vapours which are daily raised from the sea, may, with great probability be supposed to carry with them some minute portions of the acid of sea salt, and, perhaps, of sea salt in substance, and of the calcareous earth, with which the sea abounds. The atmosphere itself may be looked upon, not only as the general receptacle

ceptable of these aqueous vapours, but likewise of all mineral exhalations; of the steams, which are constantly arising from the perspiration of whatever enjoys animal or vegetable life; and from the instantaneous putrescence of those substances, when deprived of life; of the smaller seeds of terrestrial and aquatic plants; of the eggs of an infinity of species of imperceptible animalcules; of the acids and oils separated by combustion from all sorts of fuel; of the matter of light; of electric effluvia; and of a variety of other substances, which are elevated, and, for a time kept suspended, by natural and accidental causes: from these sources are derived, those various impurities, which have been discovered in all atmospherical water; and which.

which we can readily apprehend, must be different in quality and quantity, according to the nature of the heterogeneous substances subsisting in that portion of the atmosphere, through which the aqueous vapours have ascended, or which they have washed in their descent; that is, in general, according to the nature of the climate, the season of the year, the direction of the winds, and the preceding temperature of the weather.

ESSAY IV.

OF THE SALTNESS AND TEMPERATURE OF THE SEA.

THERE are few questions, respecting the natural history of our globe, which have been discussed with more attention, or decided with less satisfaction, than that concerning the primary cause of the saltness of the sea. The solution of it had perplexed the philosophers before the time of Aristotle*; it surpassed

* Arist. Meteo. L. ii. c. iii

passed his own great genius; and those of his followers, who have attempted to support his arguments, have been betrayed into very ill-grounded conclusions concerning it. Father Kircher*, after having consulted three and thirty authors upon the subject, could not help remarking, that the fluctuations of the ocean itself were scarcely more various, than the opinions of men concerning the origin of its saline impregnation.

The question does not seem capable of admitting an illustration from experiment; at least, no experiments have hitherto been made for that purpose, and therefore we may be the less surpris'd at its remaining nearly as problematical in the present age, as it has been in any of the preceding.

* Kirch. Mun. Subter. L. iii. c. iii.

ceding. Had there, indeed, any observations been made, three or four centuries ago, ascertaining the then saltness of the sea, at any particular time and place; we might, by making, at present, similar observations at the same place, in the same season, have been able to know whether the *saltness* at that particular place, was an *increasing*, or a *decreasing*, or an *invariable* quantity: and this kind and degree of knowledge would have served as a clue to direct us to a full investigation of this matter in general; but it is to be regretted, that no such observations have, till very lately, been made with any tolerable precision.—There are three principal opinions on this subject, which have been maintained by philosophers of modern date.

Some* observing that river water, almost in every part of the globe, is, in a greater or less degree, impregnated with sea salt, have thought that the sea has gradually acquired its present quantity of salt from the long continued influx of rivers. The water, which is carried into the sea by the rivers, is again separated from it by evaporation, and being dispersed over the atmosphere by the winds, it soon descends in rain or vapour upon the surface of the earth; from whence it hastens to pour into the bosom of the ocean, the fresh tribute of salt, which it has collected in its inland progress. Thus the salt conveyed into the sea, not being a volatile substance, nor performing an incessant circulation, like the wa-
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* Halley, Philos. Transf. No. 344.

ter which carries it thither, must be a perpetually increasing quantity, and time enough, it is contended, has elapsed since the creation, for the sea to acquire from this source its present quantity of salt.

The principle upon which this opinion is founded, cannot become the subject of accurate calculation; rivers may have formerly carried more or less salt into the sea, than they do at present; and the quantities, contained at present in different rivers, are so various, that any general position, with respect to the proportion of salt observable in river water, will be liable to many exceptions from particular cases. It may appear probable, however, from the following observation, that the cause here assigned of the saltiness of the

sea, is not adequate to the effect. Sea water, at a medium taken from observations made in different climates, may be supposed, without any great apprehension of error, to contain about one thirtieth of its weight of common salt; but all the rivers in the world could not have conveyed into the sea one five hundredth part of the weight of the sea, though we suppose that they have daily, ever since the creation, carried into the sea and left there, the same quantity of salt, which they do at present daily deposit in it. In order to make this out, with any appearance of perspicuity and precision, we will take for granted, what some eminent philosophers have endeavoured to prove, — “ that all the rivers in the world flowing into the
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bed of the sea, with a continuance of their present stores, would take up at least eight hundred years to fill it to its present height.*;” —this being premised, let us suppose the ocean to have been originally quite fresh, and to have daily lost by evaporation as much water, as it daily received from the influx of the rivers, then must eight hundred years have passed before the fresh water of the ocean could have been changed into river water, or acquired that proportion of salt with which river water is impregnated. River water may, in general, be supposed to contain one four thousandth part of its weight of sea salt; some rivers, doubtless, contain

* Goldsmith’s Hist. of the Earth, &c. Vol. I. p. 228. Buffon, Hist. Nat. Vol. I. p. 356.

tain more, others less, but the quantity here assumed seems to be great enough; since even the Thames* water, taken up near Billingsgate, impregnated, as it may be supposed to be, with sea salt, from the quantity of it used in London, and washed into it by various drains, does not contain one half so much; the ocean upon this hypothesis, at the expiration of eight hundred years from the creation, would have contained one four thousandth part of its weight of sea salt; and at the expiration of eight times eight hundred years, it would have contained eight four thousandth parts, or one five hundredth part of its weight of salt; but eight times eight hundred years carry

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* See an ingenious Inquiry into the Nature of Water, by Dr. Rotherham, p. 114.

us back to an æra antecedent to the creation of the world.

Other philosophers *, observing that large beds of fossil salt are not unfrequent in any quarter of the globe; and conceiving, with great probability, the bottom of the sea to be analogous in its formation to the surface of the earth, have undertaken to derive its saltiness from the beds of rock salt, which they have supposed to be situated at its bottom; and they are further of opinion, that without such a permanent saline principle, the sea would long since have become insipid from the fresh water poured into it by an infinity of rivers. Strange! that
what,

* Mem. de l' Acad. des Scien. de Ber. Ann. 1760.

what, according to the forementioned hypothesis was thought sufficient to account for the saltness of the sea, should in this be esteemed instrumental in annihilating the saltness already supposed to exist.

This opinion is liable to an objection of some weight; for it may reasonably be inquired, why the waters of the ocean are not perfectly saturated with salt, if they have ever since the creation been exerting their dissolving powers upon such permanent masses of rock salt as are thought to be situated at its bottom. Were the waters of the ocean in a quiescent state, and every where of two or three miles in depth, as they are conjectured to be in some, it would not be an easy matter to define the time in which the waters at
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the surface would become rapid, much less, in which they would become saturated, though the whole bottom of the ocean was covered with a stratum of rock salt. The water contiguous to the salt would saturate itself therewith, and being thereby rendered heavier than the superficial water, it would not readily mix itself with it; but though the lower parts of the sea have been observed by divers to remain in a very tranquil state, when the upper have been much agitated by storms; yet it may reasonably be supposed, that they are sufficiently moved, to cause, in a sufficient length of time, an uniform diffusion of the rock salt, they may be supposed to have dissolved. The patrons of this opinion found their reasoning upon a mistake;

they think, that if there were no mines of rock salt in the bed of the ocean, its waters would have been long ago converted into fresh water, by the rivers discharged into it. Now this is an erroneous principle; for supposing that the rivers themselves contained no salt, and that they returned into the sea, in any given time, the same quantity of water, which in the same time is raised from it by evaporation, the saltiness would remain precisely the same for ever. But neither of these suppositions is true, for the rivers do convey into the ocean some portion of salt every day, and they do not, in any given time, return into the ocean so much water as in the same time is separated from it; and upon both these accounts, the salt-
ness

ness of the sea, so far from being diminished, ought constantly to be increased, from the rivers poured into it.

Boyle * unites, as it were, the two preceding hypotheses, and “ takes the saltness of the sea to be supplied, not only from rocks and other masses of salt, which at the beginning were, or in some countries may yet be found either at the bottom of the sea, or at the sides, where the water can reach them; but also from the salt which the rivers, rains, and other waters dissolve in their passage through divers parts of the earth, and at length carry with them into the sea.” Buffon†, and the generality

* Boyle's Works, Vol. III. p. 381.

† Hist. Nat. Vol. I. p. 361. Goldsmith's Hist. of the Earth, Vol. I. p. 234.

rality of philosophers, acquiesce in the opinion of Boyle.

After all, it may be observed, that we are inquiring into the cause of a phænomenon, which it may be said had no secondary cause at all. It is taken for granted in this disquisition, that the water which covered the globe in its chaotic state, was not impregnated with salt as at present, but quite fresh; now this is an opinion concerning a matter of fact, which can never be proved either way; and surely we extend our speculations very far, when we attempt to explain a phænomenon, primeval to, or coeval with, the formation of the earth.

Bernardine Gomesius *, about two hundred years ago, published an ingenious

* Gomes de Sale, l. i. c. 24.

genious treatise upon salt: in this treatise, after reciting, and refuting, the opinions of Empedocles, Anaxagoras, and Aristotle, upon the subject in question, he proposes his own; wherein he maintains that the sea was originally created in the same state in which we at present find it, and impregnated from the very first with the salt which it contains. Though this hypothesis may be considered by some, rather as a cutting than any untying of the knot, yet it has been embraced by philosophers of great eminence *; and it must be owned that it may be applied to the solution of some phænomena with peculiar propriety. Naturalists assure us, that, though some few species of
fishes

* Kircher *Mun. Sub. L. iii. c. iii.*——
Nollet. *Lec. de Phys. Tom. IV. p. 62.*

fishes thrive in fresh water, and some others live alternately in fresh water and salt, yet by far the greatest number cannot exist out of the sea: now whether we suppose the sea to have become salt from the influx of rivers, or from the gradual solution of beds of rock salt, or from the combined influence of both these causes, it must for some years have remained so exceedingly fresh, that it will not be an easy matter to account for the continuation of the existence of the numberless species of fishes, which cannot live in fresh water. This difficulty is not removed by supposing that fishes do not imbibe any part of the sea's saltiness with their food, and attributing the efficacy of sea water in preserving life, to the superior weight with which it compresses the organs

of respiration, for this superior weight is as much an effect of the salt dissolved in it, as the saline taste itself. The saltiness of the *Caspian* sea, of the lakes of *Mexico*, and *Titicaca*, and of other large collections of waters, which have no effluent rivers, nor visible communication with the sea, may be as successfully explained upon this hypothesis,—that the sea was at the creation impregnated with salt — as upon either of the preceding.

Besides the opinions, concerning the cause of the saline impregnation of the sea, which have been here mentioned, there is another, which future ages will, probably, see less questionable reasons to adopt than we do: I mean that which maintains —that sea salt is constantly and abundantly

dantly generated, both on the surface of the earth, and in the bosom of the ocean.

But how ineffectual soever our attempts may be to explain the cause of the saltness of the sea; yet one might have hoped, that in this age of philosophy and curious navigation, the degree of its saltness in every latitude, and every season of the year, would have been ascertained by accurate experiments. The acquiring knowledge by experiments, is a slow and laborious method, but it is, at the same time, a method within our reach: whilst the theoretical investigation of the proximate cause of any natural phenomenon often surpasses, and that of its ultimate cause always surpasses the apprehension of the human intellect.

Some

Some experiments tending to the elucidation of this point, respecting the sameness or diversity of the saltness of the sea in different places, were made in the course of the voyage towards the North Pole, in 1773. We learn from these experiments, that the sea water at the *Nore* contained not quite $\frac{1}{30}$ of salt; at the back of *Yarmouth* sands not quite $\frac{1}{32}$; off *Flamborough Head* rather more than $\frac{1}{29}$; off *Sketland* rather less than $\frac{1}{29}$; latitude 74 at sea $\frac{1}{29}$; latitude 78 less than $\frac{1}{28}$; latitude 80, near the ice, not quite $\frac{1}{30}$; latitude 80. 30, under the ice, not quite $\frac{1}{28}$; latitude 68.46, rather more than $\frac{1}{28}$; latitude 65, at sea, rather less than $\frac{1}{28}$ *.

Hales

* These several quantities are derived from the experiments mentioned in a Voyage towards

Hales got only $\frac{1}{27}$ from water taken up in the *Mediterranean*, and $\frac{1}{29}$ from water taken up at the *Nore*. Dr. Rutty says, he got $\frac{1}{25}$ from water taken up in latitude 65; $\frac{1}{28}$ from water taken up near to *Dublin*; and $\frac{1}{30}$ from water taken up at *Dungarvan*; and Dr. Lucas, that he got $\frac{1}{25}$ from sea water taken up at *Harwich* *." The reader will observe that these experiments do not perfectly accord, as to the quantity of salt contained in water taken up at the same place, as at the *Nore*, and in latitude 65. This is not to be wondered at; the sea water in the same latitude, is not always equally di-

wards the North Pole, 1773, by Conf. John Phipps, now Lord Mulgrave, p. 143.

* Monro on Mineral Waters, Vol. I. p. 105.

diluted by the fresh water which falls from the atmosphere; nor can we be certain, that different persons, in making experiments of this kind, have always used the same degree of heat, in drying the residue which remains after the evaporation of the water; or that they have evaporated the water with the same degree of heat: and yet this circumstance alone may occasion a great disparity in the quantity of the saline matter, separable from a definite weight of sea water. For not to insist upon, what has been before mentioned, the decomposition of a part of the sea salt, which takes place when a solution of it is evaporated with a great heat, it may be observed, that the sea salt in substance is dispersed, when a saturated solution of it is evaporated with even less than

a boiling heat. This is very clearly seen, when a small quantity of a solution of sea salt is evaporated to dryness in a deep copper vessel, for the inside of the vessel, which can come in contact with nothing but the vapour, is spangled with particles of salt, which have been carried up with the vapour.

It appears from some experiments, formerly made in a voyage from England to *Bombay* in the East Indies, that the weight of the sea water was the greatest, not precisely at the Equator, but where the sun was vertical, and consequently, in similar circumstances, where the heat was greatest. The greatest weight of a definite quantity of sea water, which was observed in sailing from 28 degrees, north latitude, to the Cape of *Good Hope*,

Hope, which is about $34\frac{1}{2}$ degrees south latitude, in the months of May, June, and July, was at St. Jago island, north latitude, 15 degrees; and the least was at Tenerif island, north latitude 28. The weights of equal bulks of Thames water, of the sea water at Tenerif, and St. Jago, were 659—673 $\frac{1}{2}$ —780 $\frac{1}{2}$ grains *; the proportion of which numbers may be nearly thus expressed.—Thames water 1000,.....Tenerif sea water 1022, —St. Jago sea water 1184. By comparing these numbers with a Table in the Philosophical Transactions, exhibiting the comparative weight of equal bulks of simple water, and of water impregnated with different portions of sea salt, it may be conjectured, that the Tenerif sea water

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* Gentleman's Mag. Vol. XXV. p. 260.

contained about $\frac{1}{3^2}$ of salt, and the St Jago water above $\frac{1}{4}$ of its weight of salt, so that it was nearly, if not fully, saturated*.

As it is not every person who can make himself expert in the use of the common means, of estimating the quantity of salt contained in sea water, I will mention a method of doing it, which is so easy and simple, that every common sailor may understand and practise it; and which, at the same time, from the trials I have made of it, seems to be as exact a method, as any that has yet been thought of.—Take a clean towel or
any

* I formed the table here referred to above 10 years ago; I have reason to think, that those who have leisure and accurate instruments, might make it more correct, by using more precaution than I did in some particulars, especially in what relates to the purity of the salt. *Philos. Transf.* 1770, p. 349.

any other piece of cloth, dry it well in the sun or before the fire, then weigh it accurately, and note down its weight; dip it in the sea water, and, when taken out, wring it a little till it will not drip, when hung up to dry; weigh it in this wet state, then dry it either in the sun or at the fire, and, when it is perfectly dry, weigh it again. The excess of the weight of the wetted cloth above its original weight, is the weight of the sea water imbibed by the cloth; and the excess of the weight of the cloth, after being dried, above its original weight, is the weight of the salt retained by the cloth; and by comparing this weight, with the weight of the sea water imbibed by the cloth, we obtain the proportion of salt contained in that species of sea water.

Whoever undertakes to ascertain the quantity of salt, contained in sea water, either by this or any other method, would do well to observe the state of the weather, preceding the time when the sea water is taken out of the sea, for the quantity of salt contained in the water near the surface, may be influenced, both by the antecedent moisture, and the antecedent heat of the atmosphere. And this leads to the consideration of a question proposed by *Aristotle**, —Why are the upper parts of the sea saltier and warmer than the lower?Some philosophers admitting the fact, have followed him in attempting to explain it; whilst others have thought themselves authorized by experiment, to deny the truth of the
possi-

* *Arist. Prob. S. xxiii. 9. 30.*

position; and those, perhaps, will argue with the greatest justness, who shall affirm, that it is neither generally to be admitted, nor generally to be rejected, but that the sea in some places, and under certain circumstances, is saltier and warmer at the surface, than at any considerable depth beneath it, while in many others the reverse is true. The question consists of two parts, betwixt which, though there, probably, is a connection, yet it is not so necessary a one, as to hinder us from considering each part by itself.

As to the saltness of the sea at different depths, we have different accounts concerning it. There are two methods of estimating the relative quantities of salt contained in

different specimens of sea water; one consists in weighing equal bulks of them, suppose a pint or a bottle full of each; for if they have equal weights, it is safely enough inferred, that they contain equal quantities of salt: the other consists in evaporating a pint, or any other measure of sea water, and weighing the salt (which is not evaporable) remaining after the water is wholly dissipated. Mr. Boyle found, that equal bulks of water taken up in the *Channel* between *France* and *England* at the surface, and at the depth of fifteen fathoms, were equally heavy, and thence he concludes, that the superficial water was as salt as that at a great depth.*

On

* Boyle's Observ. on the Saltness of the Sea.

On the other hand, Count Marfilli obtained by evaporating the water, a thirty-second part only of its weight of salt from water, taken up on the surface of the sea in the gulf of *Lyons*, whilst that taken up at the same time and place from a great depth gave him a twenty-ninth part of its weight of salt; and he thence infers, the greater saltiness of the sea at the bottom than at its surface*. In this conclusion he has been supported by experiments made in the gulph of *Botnia*.

There can be no reason to suspect the accuracy with which any of these experiments was made: in different places the facts will probably be different. The *Rhone* discharges much *fresh* water into the gulf of *Lyons*;

* Histoire Phys. de la Mer.

Lyons; this fresh water being lighter than the sea water, will not readily mix itself with it, and for this reason the superficial water will be most diluted by it, and from that circumstance it will contain less salt, in a definite quantity, than the water which is at a greater depth. At Northwich they pump their brine, which is to be boiled into salt, into a very large circular bason, sunk in the ground, and lined with brick, from whence, when its impurities are subsided, it is conveyed to the boiling pans. This bason is exposed to the open air, and in case of a great fall of rain, or snow, they let off the uppermost parts of the water through a wooden tube, which is at other times stopped with a plug, placed

placed upon a level, nearly, with the upper surface of the brine in the bafon; what is thus let off is not preserved, but thrown away as useless. This practice proceeds upon the principle we are speaking of, namely, that fresh water is not apt to mix itself, unless it be much agitated with salt water. The gulf of *Bothnia* receives rivers from an immense range of mountains, extending themselves to the east, the north, and the west, far beyond the polar circle; and therefore, as in the gulf of Lyons, its surface may be more diluted with fresh water than its middle or bottom. But in the water of the *English channel*, with which Mr. Boyle made his experiment, the case is very different. This water
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has a communication with the German ocean on one side, and with the Atlantic on the other; and, from that circumstance, it is subject to such a constant agitation as will occasion all the fresh water, poured into it by the Thames, Medway, and other rivers of less consequence, to be uniformly diffused through all its substance, so as to render it equally salt at all depths. The constant effect produced on the superficial water of the sea, by the influx of a large river, is somewhat similar to the temporary effect, attending a downfall of rain; the superficial water will be thereby much diluted. It was observed in the voyage to Bombay before referred to, that if a quantity of sea water in dry weather weighed

weighed 778 grains, an equal quantity immediately after a fall of rain would not weigh above 676 grains, the same quantity of Thames water weighing 659 grains. Hence it may be collected, that the weight of a cubic foot of the sea water before rain exceeded the weight of a cubic foot after rain by 155 ounces.

In the voyage which was made towards the North Pole in 1773, we meet with some experiments on this subject.

In the open sea off Shetland, north latitude 60 degrees, equal quantities of water were taken up at the surface, and at the depth of sixty-five fathoms; these different waters yielded by evaporation equal quantities of salt, namely, $\frac{1}{29}$ of their weight nearly.

On

On another occasion, in north latitude 65 degrees, some water taken up from the surface gave nearly $\frac{1}{28}$ of its weight of salt, whilst an equal weight taken up from the depth of 683 fathoms in the same place, gave only $\frac{1}{32}$ *.

It is obvious that the first of these experiments confirms Mr. Boyle's notion of the sea being equally salt at all depths, and that the second is wholly opposite, both to his opinion, and that of Count Marfilli, so that the question remains still undecided. There is a circumstance, however, which I will submit to the reader's
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* In page 143, from which this account is extracted, the latitude is put equal to 75 degrees ; but it appears from pages 117 and 137, that the ship on the 4th of Sept. when this experiment was made, was in latitude 65.

consideration, whether it may not be sufficient to explain the different results of the experiments made during the voyage here spoken of. The experiments which gave equal quantities of salt from equal quantities of water, taken up at the surface, and at the depth of 65 fathoms, were made on the 12th of June; the others, which gave more salt from the superficial, than from the deep water, were made on the 4th of September. Now admitting the saltiness of the superficial water, and of water at the depth of 683 fathoms to have been the same, in the beginning of June, why may not the quantity of water, evaporated from the surface of the sea, during the hot months of July and August, have left the superficial water more impreg-

impregnated with salt than the water at a great depth? It is some confirmation of this notion, that the air in June was only six degrees warmer than the water from the depth of 65 fathoms, and that the air in September, when the experiment was made, was above 26 degrees hotter than the water from the depth of 683 fathoms. The rise of fresh springs at the bottom of the sea, in particular places, may be another reason for our accidentally finding the sea saltier at its surface than at any great depth below it. However, neither of the reasons here offered in explanation of the phænomenon are wholly to be relied on; for the fresh water which may accidentally be found at the bottom of the sea will rise up till it becomes as
much

much impregnated with salt, as the water incumbent over it is, and the water at the surface, which is rendered heavier by the sun's having evaporated some of its fresh particles, will probably sink downwards, and mix itself with the water below it, till the whole mass of water becomes equally heavy, and consequently equally salt. The fact itself, of the sea being in any case saltier at the surface than at its bottom, ought to be ascertained by repeated experiments.

With respect to the temperature of the sea at different depths, it seems reasonable enough to suppose, that in summer time it will be hotter at the surface than at any considerable depth below it, and that in winter it will be colder. Suppose a

cistern, twelve feet in depth, to be filled with spring water, of 48 degrees warmth, to the height of eleven feet; then if we fill up the cistern to its top, by gently pouring water heated to 100 degrees upon the surface of the spring water, it may readily be understood, that the heat of this water will not be instantaneously communicated through the whole mass of water in the cistern, but that the water will decrease in heat from the surface to the bottom of the cistern. On the other hand, if on the 11 feet of spring water heated to 48 degrees, we pour a foot of water heated only to 33 degrees, it may be expected, that the spring water which is nearest to the cold water, will be sooner cooled by it than that which is at a greater distance;

distance; and on this account the water at the bottom of the cistern will be warmer than that in the middle or at the top. It must be observed, however, that cold water being, bulk for bulk, heavier than hot water, the water which has only 33 degrees of heat will descend by its superior weight, into the mass of water contained in the cistern, and thus the water in the cistern will be cooled, not only by the bare communication of cold from the upper water, but by the actual mixture of that water with the rest, so that the difference between the heat of the water at the bottom and top, will not be so great as it would have been, if the cold water had not mixed itself with the rest. These

suppositions of hot and cold water incumbent on the spring water in the cistern, are analogous to the action of the summer and winter atmospheres incumbent on the surface of the sea. No person, who has bathed in deep standing water in summer time, can have failed to observe, that the water grew colder and colder, according to the depth to which he descended. I have frequently observed, that the surface of a pool of water of two feet in depth, has, in a sunny day, even in winter, been five degrees hotter than the water at its bottom.

Mr. *Wales* describes the instrument he made use of for trying the temperature of the sea at different depths, in the following terms:
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“ The apparatus for trying the heat of the sea water at different depths, consisted of a square wooden tube, of about 18 inches long, and 3 inches square externally. It was fitted with a valve at the bottom, and another at the top, and had a contrivance for suspending the thermometer exactly in the middle of it. When it was used, it was fastened to the deep-sea line, just above the lead, so that all the way as it descended the water had a free passage through it, by means of the valves which were then both open ; but the instant it began to be drawn up, both the valves closed by the pressure of the water, and of course the thermometer was brought up in a body of water, of the same tempera-

ture with that it was let down to*." With this instrument, which is much the same with one formerly described by Mr. Boyle, in his observations about the saltness of the sea, water was fetched up from different depths, and its temperature accurately noticed, in different seasons and latitudes.

August 27, 1772, south latitude $24^{\circ} 40'$. The heat of the air was $72\frac{1}{2}$,—of the water at the surface 70,—of water from the depth of 80 fathoms 68 †.

December 27, 1772, south latitude $58^{\circ} 21'$. The heat of the air was $31\frac{1}{2}$,—of the water at the surface

* See Astronomical Observations made in a Voyage towards the South Pole, &c. in 1772, 1773, &c. by W. Wales. Introduction, p. 53.

† Wales' Obser. p. 206.

face 32, — of water from the depth of 160 fathoms $33\frac{1}{2}$ *.

In the voyage to the high northern latitudes before mentioned, they made use of a bottle to bring up water from the bottom, which is thus described. “ The bottle had a coating of wool, three inches thick, which was wrapped up in an oiled skin, and let into a leather purse, and the whole inclosed in a well-pitched canvas bag, firmly tied to the mouth of the bottle, so that not a drop of water could penetrate to its surface. A bit of lead shaped like a cone, with its base downwards, and a cord fixed to its small end, was put into the bottle; and a piece of valve leather, with half a dozen slips of thin bladder were

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strung

* Wales' Obser. p. 208.

strung on the cord, which, when pulled, effectually corked the bottle on the inside." I have here put down two of the experiments which were made during that voyage.

August 4, 1773, north latitude $80^{\circ}. 30'$. The heat of the air was 32,—of the water at the surface 36,—of water fetched up from the depth of 60 fathoms under the ice 39*.

September 4, 1773, north latitude 65° . The heat of the air was $66\frac{1}{2}$,—of the water at the surface 55,—of water from the depth of 683 fathoms 40.

It appears from all these experiments that, when the atmosphere was hotter than the surface of the sea, the superficial water was hotter than

* Voyage towards the North Pole. p. 143.

than that at a great depth ; and when the atmosphere was colder than the surface of the sea, it is evident that the superficial water was somewhat colder than that at a considerable distance below it : and I doubt not that this will generally be the case, though sudden changes in the temperature of the atmosphere, which cannot be instantly communicated to the sea, may occasion particular exceptions.

In the year 1779, several experiments were made, with great accuracy, in order to investigate the temperature of the lake of *Geneva*, and of other lakes in Switzerland, at different depths ; we learn from them, that in winter time there is very little difference between the heat of
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the water at the surface, and at a great depth below it; but that in summer, the superficial water is considerably warmer than that which is at a great distance from the surface. The experiments were made with a thermometer graduated after Reaumur's scale; some of them, reduced to Fahrenheit's scale, are expressed below.

Temperature of the lake of *Geneva* at different depths, in the beginning of February 1779, after a month's uninterrupted frost.

Heat of the open air variable from 37 to 40 degrees.

In

Water at the surface of the lake,	42 $\frac{1}{8}$
Depth 100 feet - - -	42 $\frac{1}{8}$
Depth 250 feet - - -	42 $\frac{1}{8}$
Depth 950 feet, bottom -	41 $\frac{2}{5}$

In another part of the lake, open
air from 37 to 40.

Surface	-	-	-	-	-	$42\frac{1}{8}$
Depth 350 feet	-	-	-	-	-	$42\frac{1}{8}$
Depth 620 feet, bottom	-	-	-	-	-	$41\frac{2}{8}\frac{7}{8}$

Temperature of the lake of *Neuchâtel*, July 17, 1779.

Air	-	-	-	-	-	$75\frac{1}{2}$
Surface	-	-	-	-	-	$73\frac{5}{8}$
Depth 225 feet, bottom	-	-	-	-	-	41^*

* The reader will find a great many other experiments of the same nature, in the first volume (the only one yet published) of a very interesting work, intituled, *Voyages dans les Alpes*, par Horace-Bénédict de Saussure, Professor of Philosophy at Geneva.

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ESSAY V.

OF FRESH WATER PROCURABLE FROM
SEA WATER, BY CONGELATION,
AND BY DISTILLATION.

“**T**HE second day we descried
a main bank of ice, in the latitude of 60° . We wanting fresh water did sail close to this land of ice, and hoisted out our boat and loaded her twice with ice, which made us very good fresh water*.”—“About nine
of

* Capt. Weymouth's Voy. in 1602. Purchas' Col. B. iv. c. 13.

of the clock in the forenoon we came by a great island of ice, and by this island we found some pieces of ice broken off from the said island, and being in great want of fresh water, we hoisted out our boats of both ships, and loaded them twice with ice, which made us very good fresh water*.” — “ The pieces of ice we took up were hard and solid as a rock; the salt water which adhered to the ice, was so trifling as not to be tasted, and after it had lain on deck a little time, intirely drained off; and the water which the ice yielded was perfectly sweet and well tasted†.” — “ In the afternoon we filled our casks with
fresh

* Capt. Weymouth's Voy. in 1602. Purchas' Col. B. iv. c. 13.

† Cook's Voy. towards the S. Pole in 1773, Vol. I. p. 37.

fresh water, from the ice, which we found very pure and soft *."

Notwithstanding these testimonies of our most experienced navigators, concerning the fresh water which they procured from the thawing of the ice, they found floating in the sea; yet it might still remain a matter of doubt, whether the ice, from which the water was obtained, had been formed in the sea, and, consequently, whether sea water itself would when frozen yield fresh water. For it might, with some appearance of probability, be said, that the ice had either been formed at the mouths of large fresh-water rivers, and thence by tides or torrents drifted into the sea; or that it had been broken by
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* Phipps' Voy. towards the N. Pole in 1773, p. 60.

its own weight from the immense cliffs of ice and frozen snow, which, in countries where there are few rivers, are found in high latitudes to project a great way into the sea*; or lastly, admitting it to be formed in the sea, it might be urged, that it was formed of fresh water, not of salt. *Fotherbye*, in his voyage in 1614, esteems snow the original cause of the ice found at sea, for he observed it to be an inch thick upon the surface of the sea; and Captain Cook, from his own observations in the South Sea

* *Icebergs* are large bodies of ice filling the vallies between the high mountains. — Large pieces frequently break off from the icebergs, and fall with great noise into the water: we observed one piece which had floated out into the bay, and grounded in twenty-four fathom; it was fifty feet high above the surface of the water. *Phipps' Voy.* p. 70.

Sea, was disposed to think, that the vast floats of ice he met with in the spring, were formed from the congelation of snow*. Without doubt, the snow which falls upon the surface of the sea, being in a solid state, and, bulk for bulk, lighter than the sea water, will not readily mix itself with it; but may, by a due degree of cold in the atmosphere, be speedily converted into a layer of ice, the upper surface of this first layer of ice being elevated above the surface of the sea, will receive all the fresh water which falls from the atmosphere in the form of snow, fleet, rain, or dew; by the successive congelation of which, the largest fields of ice may at last be formed. Whether the ice found at
 sea,

* Voy. towards the S. Pole, Vol. II. p. 242.

sea, be formed according to any one or all of these ways, it is evident, that it is produced from an accumulation of congealed fresh water, and that we cannot, from the fresh water procurable from ice thus formed, conclude that the ice of frozen sea water would yield fresh water.

To a navigator, it is a matter of little consequence to determine, whence the ice which supplies him with fresh water is produced, he is sure of meeting with more than enough of it for his purpose, and he leaves it to the leisure of philosophers to decide the question, whether congealed sea water will, when thawed, yield fresh water. They have decided it by actual experiments, made with every suitable attention. Some sea water was taken up off the *North Foreland*,

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it was exposed to a freezing atmosphere, and it afforded an ice perfectly free from any taste of salt. The specific gravity of the water, produced from the melting of the ice, was somewhat greater than that of distilled rain water, and somewhat less than that of a mixture of rain and snow water taken out of a water tub. The degree of cold, in which the sea water froze, was $28\frac{1}{2}$ of Fahrenheit's thermometer, or $3\frac{1}{2}$ lower than that in which common water freezes*. The degree of cold, however, in which sea water freezes, cannot be ascertained in general, unless it can be shewn, that the sea water, taken up in different latitudes, contains equal quantities of salt, the contrary of which is probably true. And in

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general,

* Philos. Transf. for 1776, p. 251. & 373.

general, the greater the quantity of salt contained in any portion of sea water, the greater will be the degree of cold necessary to freeze it.

We had a sharp frost at Cambridge on the 21st of last December; I filled a thin phial, holding 8 ounces, with sea water, which contained $\frac{1}{32}$ of its weight of salt, and exposed it suspended from the branch of a tree, during the night of the day before mentioned, to the cold of the atmosphere. In the morning I found that a part of the water had been frozen: I poured the unfrozen part from the other, and having rinsed the ice in fresh water, so as to separate from it the salt water which adhered to it, I thawed it before the fire, and found the water which it gave to be wholly free from salt.

It had been long ago asserted by Macrobius *, that sea water was never frozen, but that the ice found at sea, proceeded from the freezing of the fresh water spread over its surface by the influx of rivers. And in modern times, the opinion, concerning the freezing of sea water, seems to have been admitted with great caution, by our most experienced navigators. They were aware, indeed, that the Baltic and other large seas, were frequently frozen quite over, but they appear to have thought that falls of snow laid a sufficient foundation for the production of that event, "without its being at all necessary for the sea water to freeze †."

I cannot conceive that there was any

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great

* Macrobius. Sat. L. vii. c. 12.

† Cook's Voy. Vol. II. p. 242.

great occasion for this cautious mode of expression, since it had been observed, above a hundred years ago, that not only sea water, but water containing double the proportion of salt commonly found in our sea water, and more than is contained in the sea water of any climate, might be frozen by the cold prevailing in our atmosphere*.

This freezing of sea water, moreover, was formerly practised, and, I believe, is still practised in several parts of the north of Europe, with a view to lessen the expence and trouble of extracting salt from sea water†. Stahl informs us of a chemist, who,
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* Boyle's Works, fol. ed. Vol. II. p. 264.

† Junck. Conf. Chem. Tab. xviii. f. 15.
And Wallerii Mineral. French Transf. Vol. I.
p. 316.

near a century ago, endeavoured to expedite the business of making salt in Sweden and Livonia, by means of frost. With this view he proposed the making large reservoirs to contain the sea water, and the pumping the concentrated brine from under the ice into proper vessels, to be boiled in the ordinary way. He obtained a patent, but a combination of salt-boilers ruined his project*.

I cannot see why this custom might not be introduced into England with great advantage. A third part at least of sea water may, by freezing, be converted into ice by the ordinary cold of our winters: this ice, consisting entirely of fresh water, may be thrown away as useless, and the re-

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* *Traité des Sels*, par M. Stahl. French Transf. 1771, p. 143.

maining two thirds, being boiled down, will give all the salt contained in the whole of the sea water; thus there would be a saving at least of one third part of the fuel employed in boiling sea water into salt *. When it is said, that the unfrozen sea water contains all the salt, this must be understood with some restriction, since it is probable, that the frozen part will, upon most occasions, hold a little salt, but not so much as is contained

* Bristol and other waters containing earth, are found to deposit their earth, or a great portion of it, by being frozen.—Brownrigg on Salt, p. 76. Some ice, taken from under the surface of the sea in *Hudson's* Streights, being melted, gave 6 ounces of salt from 40 quarts of water.—It is probable, that it would not have given so large a proportion of salt, had it been previously cleansed from the adhering sea water. *Philos. Trans.* 1740, p. 807.

tained in many spring waters, which are reckoned sufficiently pure. Eight pounds of frozen sea water, taken up near Calais, left upon evaporation 32 grains of residuum, about half of which was sea salt. The same quantity of unfrozen sea water, taken up at the same place after the frost, left by evaporation 1412 grains of residuum, so that the water, by being frozen, had freed itself from 1380 grains of heterogeneous matter*.

The ice found at sea is of different colours and consistencies, some is polished and pellucid, and thought to be fresh water ice; another kind is of a spongy texture, and of a pale green colour like vitriol; and it has been affirmed, that this kind of ice
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* Journ. des Scavans, Mai, 1769. See, also Boerh. Chem. Vol. I. p. 721.

is salt, and consists of salt water frozen *. This is a mistake, both as to the fact and the reason of it; for the vitriol coloured ice, when freed from the salt water in which it swims, is quite fresh †, and sea water when frozen, we have seen, does not yield a salt ice.

We may, perhaps, be less surprised at the particles of water, in which sea salt is dissolved, separating themselves from the particles of the salt, and coalescing together without admitting any junction with such a heavy extraneous body, when we consider, that during the action of freezing, they refuse all union even with the air itself. Water in its fluid
state

* Crantz's Hist. of Greenland, B. I. c. ii. f. 13.

† Philol. Transf. for 1770, p. 111.

state is saturated with air, but it is in a great measure, if not wholly, deprived of it by being frozen; and modern philosophers have followed the opinion of Aristotle, in attributing the insalubrity (real or supposed) of water which has been frozen, to the loss of its air *. “ The water we melted out of the ice (taken up at sea) was perfectly fresh, and had a purer taste than any we had on board. If any fault could be found with it, it was that the fixed air was
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* Non solo rigore nivalis aqua perniciosa est, sed ob aliam causam quam non pigebit aperire auctore Aristotele. Omnis aqua, inquit, habet in se aeris tenuissimi portionem quæ salutaris est — nix ergo, quæ nihil aliud est quàm aqua in aere densata, tenuitatem sui cum densaretur amisit, et ideo ex ejus resolutæ potu diversa morborum genera visceribus inseminantur. Macrobo. Sat.

expelled from it, by which means almost every one who used it, was affected with swellings in the glands of the throat. Water melted from snow or ice is known always to have this effect, and the constant use of it in mountainous countries produces those enormous wens which are common among Alpine nations *". If the loss of the water's air be the true cause of the tumid throat, observable among the inhabitants of the Alps, and of the glandular swellings here mentioned, it seems as if a very simple process would free it from this noxious quality, and restore it to its original salubrity. A simple exposure to the air, for a few days, would be sufficient for the purpose; since water, which has been

* Forster's Voy. Vol. I. p. 107.

been deprived of its air, imbibes it afresh very readily, and becomes saturated with it in no great length of time. And this readiness of imbibing air makes a material difference between the water obtained from the simple thawing of snow, and river water, though the river water itself should proceed from melted snow; for being in its course constantly exposed to the air, it will soon regain the air which it had lost by being frozen.

This may not be an improper place to observe, that several physicians have rejected the notion of the use of snow water being the cause of the wens here spoken of, and that upon good grounds. For in *Greenland*, where snow water is commonly used, these unsightly protuberances
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are never met with *; nor did I ever see one of them in *Westmoreland*, where we have higher mountains, and more snow than they have in *Derbyshire*, in which country they are very common. But what puts the matter beyond doubt is, that these wens are common in *Sumatra*, where there is no snow during any part of the year †.

The possibility of extracting fresh water from sea water by distillation, has been long known; and indeed it seems as if it could never have been questioned by those, who duly reflected upon the origin of all the fresh water we meet with on the surface of the earth. The geography of the globe is yet but imperfectly known;

* Rutton's Synop. p. 42.

† Philos. Trans. for 1778, p. 165.

known; enough, however, is known of it to convince us that a much larger portion of its surface is occupied by sea than by land. The *Atlantic* Ocean appears at first view to be larger than the whole Western Continent, and the area of the rest of the habitable world, even if we take into consideration the land recently explored in the southern hemisphere, seems as if it could not equal half that immense expansion of water which constitutes the *Indian* and *Pacific* Oceans. Philosophers have attempted by measuring the most approved maps, and by other ingenious methods, to ascertain the exact proportion between the land and sea; great precision cannot reasonably be expected to accompany this inquiry; but when
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we learn from one, that the sea covers near three fourth parts *, and from another, that it covers four fifths † of the surface of the globe, we may surely rest satisfied of the truth of the general position, that there is a much greater extent of sea than of dry land. This immense mass of salt water which surrounds the globe, is the great primary source from which all fresh water is derived. The vapour which is incessantly elevated from thence by the heat of the sun, the action of the wind, and other

* See Dr. Long's Astron. Vol. I. p. 168.

† The seas, and unknown parts of the earth (by a measurement of the best maps) contain 160,522,026 square miles; the inhabited parts 38,990,569: Europe, 4,456,065; Asia, 10,768,829; Africa, 9,564,807; and America, 14,110,874. Fergusson's Tables, p. 300.

other less obvious causes, consists, generally speaking, of fresh water, which being discharged from the atmosphere in the form of dew, rain, hail, or snow, constitutes springs, rivers, and stagnant pools. The taste of sea water is, we know, not only salt but bitter; the *common salt*, which occasions its saltness, and the *Epsom salt*, which occasions its bitterness, can neither of them be raised in vapour (in any sensible proportion) by the same gentle degree of heat with which water may be raised; in order, therefore, to obtain fresh water from sea water, we need only copy the process of nature, and distil sea water with a gentle heat. This method of obtaining fresh water from the distillation of sea water, was practised by Sir R.

Hawkins, in the reign of Queen Elizabeth: — “ Although our fresh water had failed us many days, yet with an invention I had in my ship, I easily drew out of the water of the sea a sufficient quantity of fresh water, to sustain my people, with little expence of fuel; for with four billets, I stilled a hoghead of water, and therewith dressed meat for the sick and whole. The water so distilled was found to be wholesome and nourishing*.”

Since the time of Sir R. Hawkins, a great variety of attempts have been made in our own, and in other countries, to procure fresh water from sea water; they have in general been little else than different modes of distillation, but many of the
authors

* Purchas's Collec. of Voy. B. vii. c. 5.

authors of them, either from an ignorance of the real nature of sea water; or from a design of rendering their process mysterious, have mixed different ingredients with the water either before or after its distillation. The manner of procuring fresh water, by the simple distillation of sea water, seems at present to have attained a great degree of perfection, both in *France* and *England*. M. de *Bougainville*, in his Voyage round the World, has borne honourable testimony to the utility of the machine for distilling sea water, which was made public in 1763, by M. *Poissonnier*, its inventor. Lord *Mulgrave*, in his voyage towards the North Pole, in 1773, has done equal justice to the method of obtaining fresh water from the sea

by distillation, which was introduced into the English navy, in the year 1770, by Dr. *Irving*. Whether the invention of M. Poissonnier suggested any hints to Dr. Irving, is best known to himself; but he has unquestionably added such *improvements* to that method (to say no more), as seem to have justly intitled him to the parliamentary reward of five thousand pounds, which he has obtained. The French are as jealous of the glory of their nation in arts as in arms, and the English, we trust, will never be their inferior in either; it is to this excess of jealousy we must attribute the acerbity, with which one of the best chemists of the age speaks of Dr. Irving, as having deceived the Parliament of England, by appropriating to himself

self the discovery of M. Poissonnier*.

In order that the reader may have a clear notion of Dr. Irving's method, let us suppose a tea-kettle to be made without a spout, and with a hole in the lid, in the place of the knob: then the kettle being filled with sea water, the *fresh* vapour which arises from the sea water as it boils, will issue out through the hole in the lid; into that hole fit the mouth of a tobacco pipe, letting the stem have a little inclination downwards, then will the vapour of fresh water take its course through the stem of the tube, and may be collected by fitting a proper vessel to its end. This would be an apt representation of Dr. Irving's con-

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trivance:

* Baumé's Chy. Vol. III. p. 588.

trivance : he has adapted a tin tube, of suitable dimensions, to the lid of the common kettle used for boiling the provisions on board a ship; the fresh vapour which arises from boiling sea water in the kettle passes through this tube into a hogshead, which serves as a receiver; in order that the vapour may be readily condensed, the tube is kept cool, by being constantly wetted with a mop dipped in a tub of cold sea water.

It appeared from the testimony which was delivered to the Lords of the Admiralty, by many respectable officers who were eye witnesses to an experiment, made on board the *Arrogant*, at Spithead, in January 1771, that " 80 gallons of sea water did, in twenty-five minutes, after being put into the *Arrogant's* cop-

per, and a fire made, distil in the proportion of twenty-five gallons per hour, into fresh water, perfectly well tasted, and of less specific gravity than the best spring water in that neighbourhood;" and the said officers gave it as their opinion, that 500 gallons of fresh water might be distilled in the space of 24 hours, with the same quantity of fuel in proportion to the time, as is required in the ordinary business of the ship. Every ship's kettle is divided into two parts by a partition in the middle, one of these parts is only in use when pease or oatmeal are dressed, but water is at the same time kept in the other to preserve its bottom. Dr. Irving has availed himself of this circumstance, and by filling the spare part of the copper

with sea water, and fitting on the lid and tube, he has shewn, that 60 gallons of fresh water may be drawn off, during the boiling of either of the abovementioned provisions, without the use of any additional fuel: he recommends also the preserving the water which may be distilled from the coppers in which pease, oatmeal, or pudding are dressing, as both a salutary beverage for the scorbutic, and the most proper kind of water for boiling of salt provisions.

In November, 1771, *Lord Sandwich* sent me two bottles of the best distilled water which could be prepared by Dr. Irving from sea water, desiring my observations upon it. In compliance with his Lordship's request, I made the following experiments,

ments, of which I sent him an account, without venturing to give the most distant opinion concerning the salubrity or insalubrity of the water.

— Exper. 1. Four ounces of the distilled sea water being evaporated by a slow fire, upon a silver plate, left a pellicle, which was very sensibly saline to the taste, and glutinous to the touch. — 2. Four ounces of the conduit water of Trinity college, treated in the same manner, left a pellicle, but not quite so large, nor so manifestly sapid, as that from the distilled sea water. — 3. The same quantity of common distilled water, being evaporated in the same way, left no sensible pellicle. — 4. The same quantity of common distilled water, impregnated with a small drop
of

of spirit of salt, left no pellicle upon the whole surface of the plate, but only a yellowish spot upon that part of it from which the last portion was evaporated; this spot was glutinous to the touch, and had a bitter metalline taste.—5. The same quantity of common distilled water, impregnated with two grains of sea salt, left a pellicle, similar to that left by the distilled sea water, except that it was somewhat whiter, had a less piquant taste, and a less glutinous consistency. From the 4th and 5th experiments, compared with the first, it may be inferred, that the distilled sea water, which I examined, contained a small portion of sea salt, and also a small portion of the acid of sea salt uncombined with any basis. A very
minute

minute portion of sea salt, or of the acid of sea salt, may be discovered in a large quantity of water, by the milkiness which ensues on dropping into a glass full of the water, a drop or two of a saturated solution of silver in the acid of nitre.—6. I dropped a solution of silver in acid of nitre into common distilled water; no milkiness ensued, nor was the transparency of the water changed. — 7. Into an equal quantity of the distilled sea water, I dropped an equal number of drops of the solution of silver; the water became very turbid, and a copious white precipitation ensued. These experiments shew, that the distilled sea water is not wholly free from saline particles; but it probably contains them in so small a proportion,

portion, as not to injure its salubrity in any sensible degree.

We may be the more disposed to admit the possibility of distilled sea water containing saline particles, when we reflect upon the smell of the acid of sea salt, which circulates through the houses in which salt is prepared, by boiling either sea water or brine. The vapour which arises from the pans in which salt is boiled, being caught and condensed in proper vessels, and examined by proper tests, gives indications both of sea salt in substance, and of its acid. It is not an easy matter to ascertain the precise degree of heat, in which saline particles begin to accompany the vapour which is raised from solutions of sea salt; it is probably a degree

gree far inferior to that in which water boils : at least we are certain, that saline particles are found in rain and snow water, both of which are derived from vapours raised into the atmosphere by the action of the sun upon the ocean.

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ESSAY VI.

OF CALCAREOUS EARTH, CRUDE AND CALCINED.

THE word *Calx* has been introduced into the English language from the Latin; it properly denotes the friable earth, to which some sorts of bodies are reduced by fire; the operation by which they are reduced to that state, is called *calcination*, and a very large class of bodies, from their being peculiarly subject to be converted by fire into a calx, have been deno-

denominated, by various mineralogists, *calcareous* bodies; the calx or powdery earth, procured from calcareous substances by calcination, is commonly called *lime*, more philosophically *quicklime*.

Lead, iron, tin, and several other mineral substances, may respectively be reduced by fire to the state of a calx; but the earths, obtainable from these substances by calcination, not possessing the other general qualities appertaining to the calces of calcareous substances, are not called quicklimes, but calces of this or that substance from which they are prepared.

In *Cambridgeshire*, and many of the southern counties of England, lime is prepared from the calcination of *chalk*, or, as it is here generally called, *clunch*. The kilns are inverted cones
sunk

sunk in the earth, and lined with
 brick; the base of the cone is about
 ten feet in diameter, and the depth
 of the kiln is about fourteen feet.
 One of these kilns will burn about
 150 bushels of lime in twenty-four
 hours; they use generally one bushel
 of coal for every four bushels of
 lime, and in summer, when the chalk
 is dry, they will sometimes get five
 bushels of lime, from the consump-
 tion of one bushel of coal; but coal
 being dear, the chalk is seldom well
 burned. In *Wales*, *Westmoreland*, *Der-*
byshire, and many other counties,
 they burn different sorts of *limestone*,
 some of them approaching to the
 fineness of marble. In *Holland*,
 where they have neither chalk nor
 limestone, they drag fish *shells* out of
 the sea with nets drawn by horses,

and burn the shells into lime. In the islands of the southern hemisphere they burn *coral rocks* into *chenam* or lime; and in some parts of *America* they calcine *madrepores*, and other species of coral for the same purpose. Lime may also be prepared from the calcination of all kinds of *marble*; of various kinds of *spar*; of *stalactites*, otherwise called *dropstone*, and in Derbyshire *watrick*; and of several other substances which consist of *calcareous earth*, either *pure*, or mixed with *clay* or *sand*, or other matters in different proportions. In *Cheshire*, and other countries, where they have no common materials for making of lime, it would be worth while to examine the earths which may be met with upon the surface of the ground, or at a little distance below it; for
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calcareous substances are not always united into hard compact masses, but are sometimes found in the form of earth, and that of different colours.

Calcareous substances are in some countries calcined with pit-coal, in others with the cinder of pit-coal, in others with wood, in others with peat, in others with furze; the kind of fuel seems to be of no consequence, provided the degree of heat be the same. Some sorts, indeed, of pit-coal are apt, especially when used in large quantities, to cake together, and thus hindering, in some measure, the equal diffusion of the heat, the stone remains unburned. In order that the heat may penetrate through every part of the substance to be calcined, it is usual to break it into small pieces; but if the calca-

reous stone happens to be naturally shaken or split into layers, large pieces may be calcined, by placing them so that the flame of the fuel may, in ascending, find its way between the several layers of which the stone consists. In some parts of Yorkshire, they burn pieces of this sort of stone, a foot in thickness, and a foot and a half in length, without breaking them; they use generally eight dozen of coal to a kiln, and obtain twenty-two dozen of lime, the dozen containing thirty-six bushels.

It is probable, that there is a certain definite degree of heat, to which any particular kind of calcareous substance ought to be exposed, in order to its being converted into the best possible lime. If the heat be too small, the whole of the substance will
not

not be converted into lime; and on the other hand, it is possible, that the heat may be so great as to reduce the substance to a kind of glassy *scoria*; and whenever it becomes vitrified, it will lose the properties of lime. I am aware of what is generally said, that calcareous bodies, when pure, cannot be vitrified with the greatest degree of heat; but though the heat of a chemical furnace may not be sufficient for the purpose, yet there is reason to believe that a superior degree of heat may effect a kind of vitrification; certain it is, that the lime burners are careful not to give too much heat, lest they should injure the quality of the lime. When the heat has been too violent, they, in many kilns, find several pieces of limestone co-

vered with a glassy coat, and sticking together. I do not take upon me absolutely to say, that this effect is to be ascribed to a beginning vitrification of the limestone ; it may either proceed from thence, or it may be accounted for by saying, that the ashes of the fuel adhering every where to the surface of the calcareous substance, have, in particular places, where they happen to be amassed in sufficient quantity, contributed to its vitrification. This vitrification of calcareous earth, when mixed with other substances is obvious enough in the iron furnaces, where they are accustomed to mix limestone with the iron ore, the *scoria* or *slag* of an iron furnace perfectly resembling glass.

There is a very singular experiment, which may be properly mentioned

tioned in this place. Mix well together equal weights of powdered chalk, or other calcareous body, and powdered pipe clay, put the mixture into a crucible *. Any where towards the middle of the crucible, put two solid pieces, one of pure chalk, the other of pure clay, so that they may not be contiguous to each other, but be every where severally surrounded with the mixture of chalk and clay; then by exposing the whole to a strong degree of heat for a sufficient length of time, it will be found that the mixture has been converted into

* Crucibles are round or triangular vessels of different dimensions, wider at the top than at the bottom; they are principally used for the melting of metals, and are made of clay and sand, or of clay and black lead, or of such other materials as can resist the strongest fires without melting.

into glass; and upon breaking the vitrified mass, we shall discover the two solid pieces of chalk and clay, unvitrified, and unaltered in their figure, though every where surrounded with glass. Any other sort of clay would probably answer the purpose as well as pipe-clay, but I have always made the experiment with that, as being one of the purest clays. From this experiment it is certain, that a mixture of calcareous earth and clay is reducible to glass, in a degree of heat which is not sufficient to vitrify either of these substances when pure. The clay, of which bricks and tiles are made, often contains a quantity of calcareous earth, and hence we may understand the reason why ordinary bricks and tiles are not able to resist a great degree

degree of heat: a tile covering a crucible is often quite vitrified, whilst the crucible remains unaltered, the tile being a mixture of clay and calcareous earth, and the crucible being made of pure clay and sand.

It is well known, that lime is lighter, bulk for bulk, than the chalk or stone from which it is made, some substance therefore or other is dissipated during the calcination; the nature of this substance will be inquired into hereafter, at present our concern is to ascertain its quantity. The substances which I converted into lime, were fine white marble called statuary marble; Sienna marble; fine transparent crystallized spar, of that species which mineralogists have denominated hexagonal truncated; rhomboidal opaque refracting spar;

spar; rhomboidal transparent refract-
 ing spar; all these spars from Der-
 byshire; a marble, of a blueish cast,
 called dove-marble; purple-veined
 marble; Clitheroe limestone; Pur-
 beck stone; chalk from Cherry Hin-
 ton, near Cambridge; Portland stone;
 Ketton stone from Rutlandshire, de-
 nominated *hammites*, from its being
 composed of globules resembling the
 roes of fishes. A common die is a
 little cube; if we suppose the length,
 breadth, and thickness of a die, to
 be respectively increased, till each of
 them becomes equal to an inch, foot,
 yard, or mile, then will the die be-
 come a cubic inch, a cubic foot, yard
 or mile. The weight of a cubic foot
 of water is found, by experiment, to
 be precisely equal to 1000 avoirdu-
 pois cunces. Assuming then the

weight of a cubic foot of water to be 1000 ounces, by a method, sufficiently explained in books which treat of Hydrostatics, I calculated what would be the weight of a cubic foot of each of the calcareous substances, which I converted into lime.

Weight of a cubic foot of

Water	-	-	1000	} Avoirdupois ounces.
Purple-veined marble	-	-	2750	
Sienna marble	-	-	2729	
Statuary marble	—	—	2725	
CrySTALLIZED spar	-	-	2701	
Rhomboidal opaque spar	—	—	2700	
Dove-coloured marble	-	-	2694	
Rhomboid. transparent spar			2693	
Clitheroe limestone	—	—	2686	
Purbeck stone	—	—	2680	
Chalk, near Cambridge			2657	
Portland stone	-	-	2461	
Ketton stone	-	-	2456	
Medium of the 12 sorts			2661	

It

It is unnecessary to trouble the reader with a particular detail of each experiment, in which one or other of these substances was converted into lime; he will judge it sufficient to be informed of the general method of proceeding, and to be made acquainted with the general result. The method consisted in selecting pure pieces of the several substances, and putting sometimes two, sometimes three of them into a crucible filled with sand; care was taken that the pieces neither touched each other nor the side of the crucible, the crucible was then exposed to a very strong fire for four hours: none of the pieces weighed more than an ounce, so that the fire to which they were exposed, it is apprehended, was quite suffi-

sufficient to convert them into perfect quicklimes ; they were all dry, and were weighed very accurately before and after calcination, and in the weighing after calcination great care was taken to free them from every particle of sand, and to weigh them before they were quite cold. The following table comprehends in one view the different results of the several experiments ; the first column mentions the different sorts of calcareous substances with which the experiments were made ; the second expresses in hundred weights, quarters, and pounds, the quantity of lime which a ton of each respective substance would yield by calcination ; these numbers were derived, by the rule of proportion, from the small weights used in the experiments ;

ments; the third column exhibits the weight of the matter dissipated from each calcareous substance during the calcination.

	C. q. lb.	C. q. lb.
Purple-veined marble	11 1 24	8 2 4
Purbeck stone - -	11 1 22	8 2 6
Clitheroe limestone -	11 1 17	8 2 11
Dove-coloured marble	11 1 13	8 2 15
Chalk - - -	11 1 9	8 2 19
Sienna marble - - -	11 1 7	8 2 21
Portland stone - -	11 1 4	8 2 24
Ketton stone -	11 1 2	8 2 26
Statuary marble -	11 1 1	8 2 27
Rhomboidal transp. spar	11 1 0	8 3 0
Rhomboidal opaque spar	11 0 12	8 3 16
Crystallized spar -	11 0 1	8 3 27
Med. of lime from a ton	11 1 4 $\frac{1}{2}$	
Medium loss of weight in a ton }	8 2 23 $\frac{1}{2}$	

Having

Having formed this table from my own experiments, I was willing to see what correspondence it bore with the experiments of others. Authors seldom express themselves on this subject with sufficient precision; I have met, however, with some experiments, which seem to have been made with great accuracy, and I have from them calculated the following table upon the same principle as the preceding.

Cour

	C. q. lb.	C. q. lb.
* Courcelles limestone	11 2 2	8 1 20
‡ Calcareous earth separat- ed from Marle	11 1 23	8 2 5
Calc. earth from Marle	11 1 20	8 2 8
† Chalk - -	11 1 9	8 2 19
§ Vienna limestone	11 1 0	8 3 0
* Courcelles limestone	11 0 24	8 3 4
¶ Swedish limestone	11 0 18	8 3 10
¶ Gothland coral -	11 0 12	8 3 16
¶ Fish shells - -	11 0 6	8 3 22
* Courcelles limestone	11 0 1	8 3 27
¶ Chalk - -	11 0 0	9 0 0
§ Vienna limestone	10 2 14	9 1 14
Med. of lime from a ton	11 0 20 $\frac{1}{2}$	
Medium loss of weight in a ton - }	8 3 7 $\frac{11}{12}$	

From

* Paris is principally supplied with lime from the Courcelles limestone,—the three pieces here mentioned were burned in an ordinary lime kiln for 30 hours. Mem. de l'Acad. 1747, p. 62

From the bare inspection of these tables it is obvious, that calcareous substances of different kinds and countries, do not differ much from each other in the quantity of lime which a ton, or any other definite weight of them would yield by calcination.

Though I had every reason to believe, that the experiments from which I calculated the tables were made with as much accuracy as the nature of the subject would admit;
yet

‡ *Philos. Trans.* 1773, p. 161.

|| *Edin. Ess.* Vol. III. p. 16.

† Dr. Black, to whom we are indebted for our knowledge of the constituent parts of calcareous earth. *Edin. Ess.* Vol. II.

§ Prof. Jacquin's Exam. Chem. Doc. Mey. Vienna, 1769.

¶ Wallerius, *Swed. Mem.* 1760.

yet I thought it would add greatly to their confirmation, if it could be shewn, that the quantity of lime really procured from the calcination of a ton of chalk or limestone, was not much different from the medium quantity ascertained by the experiments. I went, therefore, to one of the kilns of this country, where they burn chalk into lime; and I first weighed four bushels of chalk, which had been dried by the heat of a hot summer; the medium weight of the four bushels was $86\frac{1}{2}$ pounds: I then weighed four bushels of the lime, warm from the kiln, the medium weight of which was $66\frac{1}{4}$ pounds. Calculating, from these numbers, the weight of lime which a ton of chalk would yield, it will be found to amount to 15c. 1q. 7lb.

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—This quantity of lime being so different from what I expected, I brought a piece of the chalk to my laboratory. I then weighed it accurately, and found that a month after, though the weather was hot, it had neither gained nor lost weight. I then converted it into lime, and it gave after the rate of 11c. 1q. 19lb. of lime from a ton; or 3c. 3q. 16lb. less than what the same chalk when burned in the kiln would yield. I take this difference to be wholly attributable to the superior degree of heat, with which the chalk in my experiment was burned. It is to be wished that more coal was used in the burning of lime in this country; for if a ton of chalk, when properly burned, ought to weigh only about 11 hundred weight, and it does ordinarily

weigh about 15 hundred weight, it is obvious that the purchaser has about 4 parts in 15 which are not lime but chalk; and to this cause are to be referred the hard lumps, which are found in the lime of this country, when it is slacked; these lumps being nothing but chalk which is not burned into lime for want of a sufficient fire; the expence also of carrying 4 tons of chalk in every 15 tons of lime, is a circumstance not to be neglected.

At Pennybridge, in Lancashire, they burn a hard limestone, a Winchester bushel of this stone weighed 184lb. The same measure of the lime, when just burned, weighed 109 lb. These numbers give 11c. 3q. 11 lb. of lime from a ton of the stone.

The

The lime burned at Clitheroe, in Lancashire, is reckoned to be as good as any in the kingdom, when applied either as a manure or as a cement: a bushel up heaped of the best crude stone weighed 147 pounds, an equal measure of the same stone after calcination weighed 71 pounds; from this proportion it follows, that the Clitheroe limestone would give only 9 c. 2 q. 17 lb. of lime from a ton of the stone,—this conclusion might be rendered more certain if the medium weight of several bushels was taken. It may, however, be expected that the Clitheroe limestone should lose more weight than the Cambridgeshire chalk does, for in burning it they use at least twice as much coal, or one measure of coal to two of limestone. This propor-

tion of coal is a very great one. At Knareborough, where they burn a kind of limestone formed by petrefaction, they use 1 bushel of coal to 3 of lime.

From what has been said, it must be concluded, that calcareous substances have a very great resemblance to each other, as to the quantity of that matter which is dispersed from equal weights of them during calcination; and here a curious question presents itself, which cannot be easily decided:—Is the difference in the quantity of lime, procurable from equal weights of different calcareous substances, to be accounted for, from the different proportion in which the earth remaining after calcination is united, in the crude substance, with the volatile part dispersed
 I during

during calcination; or does it proceed from some unavoidable inaccuracy in making the several experiments?—It must be acknowledged, that it is difficult to say whether the bodies are equally dry before they are submitted to calcination, unless we knew the precise degree of force with which they imbibed and retained the humidity of the atmosphere; it is difficult also to give them exactly the same degree of heat during their calcination, and to weigh them whilst they are equally warm; the greatest attention, moreover, cannot always prevent a loss of some part of the substance to be weighed, nor a gain in weight from the accretion of some heterogeneous matter; yet, notwithstanding these, and, perhaps, other sources of error in

making the experiments, I am rather disposed to think, that the proportion in which the fixed earth is united to the volatile substance, is not the same in all calcareous bodies.

A piece of dry chalk, and the three Derbyshire spars were put into the same crucible, and exposed for four hours to the same fire; it appeared, from the experiment, that a ton of the chalk would have given 36 pounds more of lime than a ton of the spar which gave the least quantity of lime, and that the spar which gave the most lime from a ton, exceeds that which gave the least by 27 pounds.

I made another experiment with the same view. Six different calcareous substances, which had been kept in the same room for a month,

or

or more, were put into the same crucible, and exposed to a very strong fire for 24 hours. I weighed them all whilst they were warm, and the quantities of lime which a ton of each would have given, with that degree of heat, are expressed in the following table:

	C.	q.	lb.
Chalk - - -	11	1	6
Clitheroe limestone	11	0	22
Sienna marble -	11	0	8
Statuary marble	10	3	21
Rhom. spar -	10	3	2
Crytallized spar	10	1	26

From this experiment it may be inferred, that the difference between the quantities of lime earth, procurable, under similar circumstances, from a ton of chalk, and a ton of hard transparent crytallized spar,

is

is 92 pounds, or near $\frac{1}{24}$ of the whole weight.

Whether this difference be greater than what might arise from different specimens of the same *kind* of calcareous substance, is more than I dare positively affirm. One specimen of the Courcelles limestone, we have seen, gave after the rate of 11 c. 2 q. 2 lb. from a ton of the crude stone; another calcined in the same kiln gave only 11 c. 0 q. 1 lb. from a ton, the difference is 57 pounds, or about $\frac{1}{40}$ of the whole weight. Different pieces broken even from the same lump of chalk, limestone, marble, and almost every other calcareous substance, seldom consist of precisely the same materials; this is obviously seen in buildings and pavements, made either
with

with marble, Ketton, or Portland stone; there may generally be observed hard knobs, which do not wear away so fast as the other parts of the stone; and those who are accustomed to saw any of these substances are fully sensible of this diversity of structure in the same block of stone, from the greater difficulty of cutting some parts of it than others. I broke the same small lump of chalk into four different pieces, and calcined them for different lengths of time, with a view of seeing whether there was not some regular proportion with respect to the time according to which the quantity of lime procurable from chalk would vary. I broke also the same lump of Clitheroe limestone into four small pieces, and calcined them

them for different lengths of time with the same intention; the result of the experiments is expressed in the annexed table.

	Lime from a ton of
Chalk calcined 4 hours	11 1 21
7 hours	11 2 18
10 hours	11 2 14
24 hours	11 1 6
Clitheroe limestone calc. 4 hours	11 1 17
7 hours	11 0 1
10 hours	11 1 9
24 hours	11 0 22

The reader will perceive that these experiments did not answer my intention in making them, since there does not appear to be any regular decrease of lime with the increase of the time of calcination; but they probably point out to us a difference in

in the composition of the different specimens ; and, indeed, in the chalk which was burned for 7, as well as in that which was burned for 10 hours, I could discern, after calcination, some small specks of iron which were wholly invisible before calcination.

Mr. Whitehurst * has favoured the world with some very interesting observations, concerning the *strata* in Derbyshire ; the following is his account of their respective thickneſſes, and of the order in which they ſucceed one another ; No. 1. denoting the uppermoſt *ſtratum*.

* See his Appendix to the Inquiry into the State of the Earth.

1. Grit

1. Grit	-	120 yards
2. Shale	-	120
3. Limestone		50
4. Toadstone		16
5. Limestone		50
6. Toadstone		46
7. Limestone		60
8. Toadstone		22
9. Limestone not cut through.		

These several strata of limestone, are each of them divided into layers, which have very different appearances. Thus No. 3. which is 50 yards in thickness, may be considered as consisting of 5 distinct layers. The 1st layer, which is contiguous to the shale, is the black Derbyshire marble; the 2d is called by the miners, snail horn marble, from its abounding with screw-stones, and fish shells; the 3d is a compact grey limestone, with several large crystalline specks in

in it, but with few shells; the 4th has rather less specks, and is whiter than the 3d; the 5th layer, which lies immediately over the toadstone, is likewise a grey limestone. I examined the relative weights of the black marble, and of the second, third and fourth layers of the stratum, No. 3. with great attention, and also the quantities of lime which a ton of each would yield; the several specimens were calcined in the same crucible, for the same length of time.

Weight of a cubic foot of the crude stone.		Weight of lime from a ton.	
	Ounces.	C. q. lb.	
Layer 1.	- 2690	11	2 7
2.	- 2685	11	1 7
3.	- 2640	11	0 15
4.	- 2650	11	1 4
Medium	2666	11	1 8 $\frac{1}{4}$

It

It appears from these experiments, that these 4 layers of the same stratum of limestone, do not lie in the earth according to their weights, the uppermost layer being the heaviest, and the third layer being lighter than that either immediately above or below it. The quantity of lime, which a ton of each would yield, seems to have some dependence on their weights; the heaviest layer yielding the most, and the lightest layer yielding the least lime from the same weight of stone *.

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* This observation is not true, I think, concerning calcareous substances in general, for a piece of Derbyshire watriele, which was 30 ounces in a cubic foot heavier than the Derbyshire black marble, being calcined in the same crucible with the marble, gave only 11 c. 0 q. 11 lb. of lime, which is 52 pounds in a ton less than the marble gave.

I have now given an account of 12 experiments made by other authors, and of 32 made by myself, on calcareous substances of different kinds and countries, the medium quantity of lime procurable from a ton of these substances, will be found to amount to 11 c. 0 q. 25 lb. and consequently the medium loss of weight will be 8 c. 3 q. 3 lb.

When compact masses of any sort of lime are exposed to the air, even in a room sheltered from rain or dew, they soon begin to crack, and in no great length of time they fall into a powder, and receive a considerable increase of weight. The time requisite for effecting this change, depends much upon the quantity of the surface of the lime, which is exposed to the air, partly, I believe, but I am

not certain, upon the degree of humidity reigning in the atmosphere, and partly upon the nature of the body. A piece of statuary marble was converted into lime on the 10th of Feb. 1779; before its calcination it weighed 540 grains, after calcination and whilst it was yet warm from the fire, it weighed 304 grains; this last quantity was laid upon a piece of clean paper, put into a drawer of my study table, and weighed at different intervals, till it had acquired its utmost increase of weight, which it attained on the 4th of March, it then weighing 515 grains. I weighed this lime for two months afterwards, at different times, but it still weighed the same. Another quantity of lime from statuary marble, was examined in the same way, and it acquired

quired its greatest increase of weight in twenty-two days. It did not seem to me, that any other kind of calcareous substance, when reduced to lime and exposed to the air, acquired its greatest increase of weight so speedily as statuary marble; I make this observation with diffidence, for I have neither tried all the sorts of calcareous substances, nor any of them under precisely the same circumstances. There is far greater trouble in making experiments, than those, who have not been accustomed to the business, can readily conceive; many niceties are to be attended to, the least of which being omitted, the conclusion becomes doubtful; the mind, moreover, having once acquired the striking outlines of knowledge, has not always

patience to attempt the filling up the minuter part of the design, especially if its attention can be but accidentally employed upon the subject.

Whoever undertakes to ascertain the time in which lime, prepared from different substances, acquires its greatest increase of weight by exposure to the air, would do well to take equal quantities of the limes, whilst warm from the fire in which they were made, to reduce them immediately to powders equally fine, to expose the powders to the air, in a room free from dust, and to weigh them at stated intervals. Or the experiment may be varied by taking, instead of powders, equal in weight and fineness, solid pieces equal in bulk and surface, suppose a cubic inch of each sort, and I question not
but

but some interesting conclusions, relative to the attractive powers of the different substances, might be derived from experiments of this sort, carefully and repeatedly made.

The powders into which the limes of different substances are resolved by exposure to the air, have not all the same appearance; those of statuary marble, dove marble, Portland stone, Ketton stone, and, probably, several other sorts, are composed of little globules visible to the naked eye; whilst those of chalk, Sienna marble, and spar, have no appearance of globules, nor do they feel so harsh and gritty to the touch, as the others do. The whitest of all the limes, which I have ever seen, is that which may be obtained from the crystallized spar before mentioned; statuary marble,

and Portland stone, give very white limes, but they are many degrees less white, than that from crystallized spar. The limes from Sienna marble, chalk, rhomboidal spar, and Ketton stone, have a yellowish cast.

Several experiments were made in order to ascertain the utmost increase of weight, which different sorts of lime can acquire by exposure to the air. The limes were all loosely folded up in clean paper, laid in the closet of a room where there was a constant fire, and weighed at different intervals, till they had acquired their greatest increase of weight, which some of them did not do in less than three quarters of a year. The general result of the experiments is expressed in the following table; where the first column contains the names

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of the substances, from which the limes were prepared; the second expresses the height to which a ton of each sort of lime would increase by exposure to the air, and the third shews the quantity of the increase in a ton.

	C. q. lb.	C. q. lb.
Sienna marble - -	35 0 12	15 0 12
Dove marble - -	35 0 9	15 0 9
Portland stone - -	34 3 21	14 3 21
Statuary marble -	34 2 0	14 2 0
Rhomboid. transf. spar	34 0 16	14 0 16
Purbeck stone - -	34 0 8	14 0 3
Crytallized spar -	33 1 25	13 1 25
Rhomb. opaque spar	32 1 21	12 1 21
Clitheroe limestone	32 1 15	12 1 15
Ketton stone - -	31 3 13	11 3 13
Chalk - - -	30 2 9	10 2 9

Hence it is evident, that the greatest increase of weight which a ton of

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lime,

lime, of the several forts here mentioned would acquire by exposure to the air, amounts to rather more than three quarters of a ton, and the least amounts to above half a ton. This observation is worthy of notice in a practical view; lime is sometimes sold by weight, and it is obvious, that the seller will be a very considerable gainer, if, after having drawn his kiln, he lets his lime remain exposed to the air for a few days before it is sold. I have frequently observed pieces of new-burned lime, daily increasing at the rate of one hundred weight per ton, for the first five or six days. The farmer too, in liming his land, should contrive to carry out his lime as soon as possible after it is burned, he may otherwise for every

every ton, have the trouble of carrying a ton and a half, or more.

Lime which has once acquired its greatest increase of weight, does not lose any part of what it has acquired by subsequent exposure to the air, even during the heat of summer. Several sorts of lime, which I apprehended had gained their greatest increase of weight in April and May 1779, were weighed at different times during the summer of the same year which was frequently very hot, but I did not observe that any one of them was diminished in weight by the action of the heat: let the matter, therefore, which is attracted by the lime from the air be what it may, it is a permanent substance, and not subject to evaporation during summer. Hence it
can-

cannot be doubted, that the soil upon which lime is spread acquires a great increase of matter; every ton of lime attracts above half a ton of some sort of matter or other from the air, and adds it to the earth; now this matter would not have become united with the earth without the intervention of lime: but whether any part of the advantage of liming, where the soil is bad or scanty, may be attributed to this increase of the quantity of matter which is derived from the air to the earth, is a question which I have not skill enough in agriculture to decide.

I have been told by a gentleman of fortune in Derbyshire, that he has frequently, with great success, spread 1000 Winchester bushels of
lime

lime upon an acre of ground : let us suppose a Winchester bushel of Derbyshire lime to weigh 100 pounds, then will 1000 bushels weigh 100000 pounds, or above 44 tons ; and supposing one ton of such lime to gain only 14 hundred weight by exposure to the air, then will the whole acre receive an increase of soil, from the lime which is spread upon it, equal to above 30 tons in weight beyond the weight of the lime.

Having estimated the loss of weight sustained by different calcareous substances during their calcination, and also the gain of weight which the limes procured from these substances acquire by exposure to the air, it is natural to inquire whether the gain is equal to the loss. Upon the 6th of March I converted

into lime 204 grains of dove marble; the lime weighed whilst hot, 116 grains; upon the 5th of the following November the lime weighed $203\frac{1}{2}$ grains. This lime was frequently weighed from March to November, and if it should be supposed that half a grain was insensibly lost by frequent weighing, then we must conclude that this kind of lime gains by exposure to the air, just as much as the marble it is prepared from loses by calcination. Upon a repetition of this experiment with another specimen of the dove-marble lime, I found the result to be, as accurately as can be expected, the same. If we make no allowance for any loss of weight by repeated weighings, then the increase of weight by exposure to the air must be esteemed less

less than the loss of weight by calcination, by about one four hundredth part of the weight of the marble.

Some dry chalk, weighing 120 grains, was reduced by calcination to 68 grains of lime; this quantity of lime became, by exposure to the air, when it had acquired its utmost increase of weight, 104 grains; that is, it wanted 16 parts in 120, or between one seventh and one eighth of the original weight of the chalk.

The dove marble and the chalk are the two extremes of all the substances I have tried; no kind of lime regained so much weight as that from dove marble, and none so little as that from chalk. Philosophy may be well employed in accounting for this diversity; I am only interested

terested at present in establishing the fact, which seems not to have been sufficiently understood by chemists of deservedly great eminence. M. Macquer says "quicklime combines with the moisture of the air which it seems capable of attracting, by the moisture thus attracted, the weight of the quicklime is doubled*." M. Baumè weighed some lime very accurately, and though he kept it in
a cellar

* Chem. Dict. by M. Macquer, artic. Quicklime in the English translation :—The original of this work is excellent in its kind, and it is greatly improved by the very judicious notes of the translator. In justice to M. Macquer, it ought to be observed, that in the second English Edition of his Dictionary, the passage quoted in the text is greatly altered, there is no mention made of the *moisture* of the air, and the quicklime is only said to recover a *great part* of its original weight, by exposure to the air.

a cellar for several years, yet it never regained the weight of the calcareous earth, from which it had been prepared; there was always a deficiency of more than two ounces in a pound*.

I do not question the veracity of either of these gentlemen, or their accuracy in making their experiments; but the properties of the particular limes which they examined should not have been given as characteristic properties of limes in general. No lime that I ever tried was doubled in weight by attracting matter (be it moisture or other matter) from the air, yet if a limestone could be found, which is not impossible, that lost half its weight by calcination, a specimen of lime from such a limestone

* Chymie par M. Baumè, Vol. I. p. 177.

stone might, perhaps, be doubled in its weight. On the other hand, I only met with one sort of lime, that from chalk, which in its increase seemed to fall so far short of the original weight of the substance from which it was made, as to want more than two ounces in a pound, or between one seventh and one eighth of the whole weight. My experiment in this particular instance, sufficiently coincides with the too general observation of M. Baumè.

The chalk or clunch of this country is not a pure calcareous earth, it contains a portion of sand; and hence, when a definite weight of this chalk lime is exposed to the air, it cannot acquire as much increase of weight, as the same quantity of purer lime would do: for the sand, which

which is mixed with the lime, is of a very different nature from the lime, and does not attract any thing from the air. This observation may be extended to different sorts of limestone, and it may suggest one reason for the diversity, in the strength of different sorts of lime, when used either in building or in agriculture.

The table in which the increase of weight acquired by different sorts of lime, in consequence of their exposure to the air, is expressed, was made with great accuracy; yet is it not to be considered as universally true, even of the substances there mentioned: for there is great reason to believe, that the quantity of matter, which the same sort of lime can attract from the air, depends very much upon the degree of heat with which

the lime has been burned ; there is a certain definite degree of heat requisite to make the lime attract the greatest possible quantity from the air. When the heat is not sufficient to convert the whole of the substance into lime, then that part which is not changed into lime, will not contribute any thing to the increase of the weight of the lime when exposed to the air, inasmuch as it possesses no quality of attracting any thing from the air. And, I believe, the observation is equally true, when the heat has been *more* than sufficient to convert the whole of the substance into lime. It has been before mentioned, that six different calcareous substances were changed into lime, by being exposed to a very fierce fire for 24 hours: this
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experiment was made in November, 1779; I have frequently weighed the limes since that time; they have all of them acquired their greatest increase of weight; for on weighing them in January, 1781, I found that they had not gained any increase of weight in an interval of three months. The following table expresses, in the second column, the increase of weight which a ton of these substances would have gained, and the third column expresses the increase which a ton of the same substances would have gained, had they been only exposed to the same fire for 4 hours.

		C. q. lb.	C. q. lb.
Sienna marble	-	8 1 15	15 0 12
Rhomb. spar	-	8 1 5	14 0 16
Statuary marble	-	8 0 0	14 2 0
Chalk	-	7 1 13	10 2 9
Clitheroe limestone	-	6 2 9	12 1 15
Cryſtallized ſpar	-	6 0 0	13 1 25

Theſe experiments clearly prove
 the great utility of burning lime
 with a definite heat, for the excel-
 lency of lime, to whatever purpoſe
 it be applied, depends, probably,
 upon its diſpoſition to attract that
 matter from the air, which it has
 loſt by calcination; and we ſee that
 none of the limes, which were burn-
 ed for 24 hours, attracted ſo much
 from the air, as thoſe did which
 had been more moderately burned;
 the difference is very conſiderable
 in all the inſtances. Would not a
 greater

greater degree of heat have still further deprived lime of its property of attracting matter from the air, and thus have made it approach nearer to the nature of glass?

We have seen how greatly calcareous substances are diminished in weight by being calcined,—do they receive any alteration of bulk during that operation? Having proposed this question to various lime-burners, in different parts of the kingdom, I found some were of opinion that the chalk or stone swelled a little, others that it shrunk a little during calcination, and a third set thought that it underwent no sort of alteration: the most obvious inference from these different accounts seems to be, that calcareous substances do in this particular differ from each other.

I took a piece of blackish marble four inches in length, half an inch broad, and one quarter of an inch thick, and having placed it in a proper vessel, and covered it with sand, it was exposed to a very fierce fire for three hours; the marble thereby became perfectly white and friable as calcined bones, but I could not observe that it had undergone the least change in any of its dimensions.

I cut a piece of chalk till it was an inch in length, half an inch in breadth, and as much in thickness; after it was calcined, its dimensions were not sensibly altered.

A piece of rhomboidal spar from Derbyshire, and a piece of white marble, were severally measured before

before and after calcination, but no difference could be observed in the dimensions of either of them.

I thought the length of a piece of Sienna marble, in one experiment, was diminished about one fiftieth part by calcination, but I was probably mistaken; for in another piece, above two inches in length, I took, with a pair of compasses, the distance between two points upon its surface before calcination, and found that distance precisely the same after calcination.

A piece of Clitheroe limestone, which had been calcined for four hours, appeared to be diminished in length one part in twelve; another piece which had been calcined ten hours, was unaltered in length, and

thickness; and so was a piece which had been calcined 24 hours.

I took a piece of chalk, which had been dried by the sun and air, and having shaped it into a square, each side of which was four inches, the thickness being two inches, I put it into a lime-kiln; it was kept there as long as chalk which is burned into lime usually is; when it came out of the kiln, I compared it with the standards of its several dimensions, which had been accurately taken before calcination, and could not discover that it had suffered the least change either in length, breadth, or thickness. This experiment was repeated with wet chalk, but neither was this altered in its dimensions by calcination. Lastly, I took a flat piece of chalk, about
one

one fourth of an inch in thickness, and calcined it for 24 hours; the length of this chalk was three inches, and it was diminished by calcination one tenth of its length.

The reader is possessed of all I know from my own experiments upon the subject; but I will not conceal from him the opinion of M. Baumè, who esteems the diminution of the bulk of calcareous substances during calcination, as one of their most distinguishing properties. He does not, indeed, mention any experiments which he had expressly made, with a view of deciding the question, but I cannot suppose, that so able a chemist would speak from conjecture, when he affirms, that calcareous substances are sometimes diminished half their bulk

bulk during calcination*; and therefore I should apprehend, that the calcareous substances, which he used, were different from any of these on which I made my experiments. Be this as it may, his conclusion is, if at all, certainly not generally to be admitted.

The experiments, by which the nature of any particular sort of earth is chemically investigated, are principally of two kinds; one consists in observing its solubility or insolubility in different menstruums, the other in
noticing

* Le second phénomène que la terre calcaire présente après sa calcination, est sa diminution de volume — la retraite de ces parties, pendant leur calcination, est quelque fois si grande, qu'elle va jusqu' à la *moitié* de leur volume. Chym. par M. Baumé, Vol. I. p. 182.

noticing the changes produced in it by the action of various degrees of heat. We may form a general idea of the operation of fire upon calcareous substances, from the experiments which have been before related; I did not spare either time or labour, nor was I sensible of any want of care in making them; yet I cannot help apprehending, that a numerous repetition of similar experiments might lead to some general conclusions, which have escaped my observation. The following experiments can hardly fail of being acceptable to the reader, as they tend greatly to corroborate what has already been inferred concerning the nature of calcareous earths. We have concluded, that twenty hundred weight, or a ton of any calcareous substance, consists
of

of between eight and nine hundred weight of some matter or other, which is dissipated during calcination, and of between eleven and twelve hundred weight of earth, which cannot be dissipated in that degree of heat: now if it can be shewn, by a way wholly different from that of calcination, that a ton of any calcareous body does really consist of about twelve hundred weight of earth, and of about eight hundred weight of a volatile substance, we cannot entertain any further doubt concerning the proportion of the constituent parts of calcareous substances.

If the reader has not been accustomed to the making of chemical experiments, and yet should be desirous of ascertaining, from his own observation, the truth of such as I am
going

going to mention, he may do it at a very easy rate; he need only procure from his apothecary, a few ounces of the acid of sea salt, and a Florence flask, and he will be furnished with the main part of the apparatus.

I took a Florence flask, and poured into it a small portion of the acid of sea salt diluted with water; the flask and its contents were then weighed in a pair of scales, which turned with a quarter of a grain; the weight was noted down. I then dropped into the acid, by a very little at a time, 20 grains of a calcareous substance, and stopping gently the top of the flask with my finger, till the whole was dissolved, the flask was weighed again. Now it is obvious, that if nothing had escaped during the solution, the weight of the flask
and

and its contents, after the solution of the calcareous substance, would have exceeded its weight before solution by 20 grains. There was, however, a very considerable loss of weight, in all the substances which I tried. If instead of 20 grains, a ton, or 20 hundred weight of each substance, had been dissolved, and no notice had been taken of any weight less than $\frac{1}{4}$ of an hundred weight, the weight of the earth, or other matter remaining in the bottle after solution, would have been expressed by the second column of the following table, and the weight of the matter lost during solution by the third.

Namure

	C. q. lb.	C. q. lb.
Namure black marble	13 3 06	1 0
Clitheroe limestone	13 1 06	3 0
Chalk —	12 3 07	1 0
Ketton stone —	12 3 07	1 0
Portland stone —	12 1 07	3 0
Purbeck stone —	12 1 07	3 0
Mother of Pearl -	12 2 07	2 0
Dove marble —	12 0 08	0 0
Blue-veined marble	12 0 08	0 0
Purple-veined marble -	12 0 08	0 0
Statuary marble —	12 0 08	0 0
Rhomboidal spar —	12 0 08	0 0
Crytallized spar * —	12 0 08	0 0

The

* Six out of the thirteen substances here examined, lost 8 parts in 20 during their solution, which is the very proportion assigned by Dr. Black, in his most ingenious Essay (Edin. Ess. Vol. II. page 104), for the loss sustained by chalk; it will appear, however, from what follows, that pure calcareous substances probably lose 9 parts in 20 of their weight, by being dissolved in an acid.

The Namure black marble and the Clitheroe limestone, threw up an oily scum during solution, and left a large portion of black sediment, which probably was iron. The chalk had a whitish sandy sediment, the Ketton stone a yellowish one, Portland and Purbeck stone a white one, which looked like particles of sand, and was gritty between the teeth; Mother of Pearl left several soft insoluble flakes floating on the top of the acid, the other bodies either gave no sediments, or very minute ones.

When I first began making these experiments, I was accustomed to weigh the flask as soon as the solution was ended, and this led me into an error in estimating the quantity lost during solution; for, upon further trial, I always found, that the weight

weight of the flask and its contents, taken, as accurately as possible, as soon as the solution was finished, was diminished very sensibly in the space of three or four hours. I was at first inclined to attribute this diminution to the evaporation of a part of the fluid; but the true cause is this, the weight of the air remaining in the flask after solution, is greater than the weight of an equal bulk of atmospherical air. This is easily proved, either by sucking through a pipe the air contained in the flask, or blowing it out with a pair of bellows, so that the flask may be filled with common air; for the flask will then be found to weigh less than it did before. Sucking out the air is a troublesome operation, for the air has a disagreeable taste in the mouth,

and if suffered to pass into the lungs, might be noxious. This disagreeable taste is not to be attributed to any subtle particles of the acid, which may be supposed to float in the inside of the flask, but to the air contained in it; for after the air has been thoroughly exhausted, so that the flask becomes full of only common air, no further taste is perceived.

I took a Florence flask, which would hold 26 ounces troy of water; into this flask I poured a two-ounce measure of the acid of sea salt, and dissolved slowly in the acid a quantity of the purest calcareous spar, the bottle was weighed as soon as the solution was ended: I then permitted it to stand quiet for two hours, and at the expiration of that time, I blew into it with a pair of bellows, till

1

the

the air became tasteless ; the bottle was then weighed, and it had lost 7 grains. The weight of common air filling a flask, holding 24 ounces of water, is about 14 grains; the weight of the same quantity of the kind of air which filled the flask, immediately after the solution of the calcareous substance, was 7 grains more, or 21 grains ; hence the weight of common air, is to that of the air which filled the flask after solution, as 14 to 21, or as 1 to $1\frac{1}{2}$. I do not offer this conclusion to the reader as an accurate one, but it is probably not far from the truth.

The circumstance of the weight of the flask being greater, immediately after the solution was finished, than it would have been if filled only with common air, was not neglected in

making the experiments mentioned in the table; it was not, however, attended to with such a scrupulous exactness, as it ought to have been: I made therefore the four following experiments with the greatest care. The several solutions were slowly made, to prevent any loss of the acid, and the flask was not weighed till 20 hours after the solution was finished; in which time the air in it had become tasteless; nor did the flask and its contents suffer any further diminution of weight, by a longer exposure to the air.

120 gr. of white marble lost by solut.	53½ gr.
120 gr. of crystal. spar lost by solut.	54 —
120 gr. of rhomb. spar lost by solut.	54 —
120 gr. of Matlock petrefaction	— 54 —

The loss of weight sustained by the marble during solution is so nearly

nearly the same with that of the other three bodies, that its difference may probably be referred to some unavoidable inaccuracy in making the experiment; if this be admitted, we may reasonably conclude that equal weights of pure calcareous substances, contain equal quantities of a volatile matter, which is dispersed during solution, and that this volatile matter amounts to 54 parts in 120, or nine hundred weight in a ton, the earth amounting to 11 c.

Since calcareous substances lose nearly equal portions of their weight, whether they are calcined in the fire, or dissolved in acids, it may be presumed that the matter which is lost is of the same nature in both cases; this matter is a species of air. The reader may easily convince himself of

this by fastening a flaccid bladder over the mouth of a Florence flask, or other vessel, in which any calcareous substance is in the act of solution, for the bladder will presently be blown up, by the matter which issues through the neck of the flask; and if the neck of the inflated bladder be tied, and the bladder be in that state removed from the flask, it will not become flaccid again, but remain blown up, which is a sufficient proof that it is filled with a species of air. The air thus separated from calcareous substances, is very different from common air, in many particulars. We have before seen, that the weight of a given bulk of this air, is as much greater than the weight of the same bulk of common air, as 21 is greater than 14, or as 3 than

than 2.—The air, it has also been remarked, has a singular taste, and common air has no taste.—This air extinguishes flame and animal life, and common air supports both.—This air by being shaken in contact with water, or otherwise mixed with it, impregnates the water with an acidulous taste, but common air produces no such effect on water.—This air is as much a constituent part of the atmosphere as common air is, for a ton of lime will attract half a ton of this air from the atmosphere. The particles of matter constituting light, are supposed to be of different magnitudes: are the particles of matter which constitute atmospherical air of different magnitudes?—Does the smell of a room newly plastered, proceed from particles of matter

Q 4 emitted

emitted by the plaster, or from the air of the room having undergone a decomposition, in consequence of the lime having absorbed one of its component parts?

When any calcareous earth has been dissolved in an acid, it has lost its air, and is much diminished in weight; it has undergone as great a decomposition, as if it had been calcined. Calcined calcareous earth or lime, may be restored to the state of crude calcareous earth or limestone, by exposure to the air; in consequence of such an exposure, it, in a greater or less space of time, attracts from the air a part at least of the principle which it had lost during calcination; but when a calcareous earth has been dissolved in an acid, and is thereby deprived of its air, it may

may be wholly restored to the state of a crude limestone, by an almost instantaneous process. Suppose 20 pennyweights of marble to have been dissolved in a proper quantity of the acid of sea salt, then will these 20 pennyweights have lost nine parts of their weight; the earth remaining in the acid will only weigh 11 pennyweights. Salt of tartar, pot ash, and other fixed alkalies contain, in their crude state, a great portion of *fixed air*, of the same nature with that which constitutes nine parts in 20 of the substance of marble, and other calcareous bodies. The acid of sea salt, and all other acids, have a stronger tendency to unite themselves with the earthy part (if the expression may be admitted) of fixed alkalies, than to continue united with the earthy

earthy part of marble, or any other calcareous body. If then into the acid, in which 20 pennyweights of marble have been dissolved, and which really consists of the acid united with 11 pennyweights of earth, we pour a solution of salt of tartar, or pot-ash, the acid will quit the earth of the marble, and unite itself with one of the constituent parts of the alkali; the earth of the marble is by this means set at liberty, and one of the constituent parts of the alkali is also set at liberty, namely, its fixed air; these two will unite together, and by their union, they will form an earth of the same nature as crude limestone, the weight of which is found to be equal to the original weight of the marble, or 20 pennyweights.

From

From the various experiments which have been here faithfully related without any previous attachment to system, it seems as if we might conclude, that pure calcareous substances are composed of 9 parts in 20 of a volatile substance, which is dispersed, not only during the calcination, but during the solution of the substances in an acid, and of 11 parts in 20 of an earth which is generally known under the name of lime. Several authors of distinguished reputation in Chemistry have thought, that *water* was an essential constituent part of calcareous substances, and from particular instances they have endeavoured to ascertain its quantity in general.—The experiments which I have made do not tend to establish this opinion.

—Into

—Into a new glass retort I put two ounces of crystallized spar, and having fitted a clean receiver of flint glass to it, I exposed it at first to a gentle fire, which was increased, by degrees, till it became strong enough to melt the retort; during the whole of the operation I did not observe that any water was separated from the spar, the transparency of the receiver was not so much as tarnished by a vapour. From this experiment I would conclude, that this species of calcareous earth does not contain any water which is separable from it in a degree of heat sufficient to melt glass. I took an earthen retort, and put into it six ounces of crystallized spar, and exposed the retort to a very strong fire till the spar had lost one third of its weight, there

there was not a drop of water found in the receiver. The retort, when taken out of the fire, appeared to be cracked, so that this experiment is not quite so convincing as the preceding, though, perhaps, sufficiently so to make us doubt concerning the existence of water as a component part of this kind of spar. —I took 720 grains of Derbyshire wattricle, which is the substance of which the ornamental columns seen on chimney pieces are generally formed, and distilled them with a violent fire in an earthen retort, till they were reduced to 400 grains (that is, till they gave after the rate of 11 c. oq. 12 lb. of lime from a ton of the wattricle), but I did not find any sensible portion of water in the receiver; it was indeed clouded with a
vapour

vapour, but this vapour I think arose from the dampness of the retort, or of the substance used in fastening the receiver to the retort, or from something or other unconnected with the watricele.—

ESSAY VII.

OF CLAY, MARLE, AND GYPSEOUS
ALABASTER, OR PLASTER-STONE.

ARgillaceous earth, or clay, may be distinguished from every other sort of earth, by its tenacity when wetted with water, and by its growing hard when exposed to the fire. We may levigate sand, chalk, or plaster-stone into very fine powder, but these powders when kneaded with water, will not form a tenacious

cious ductile mass, capable of being moulded and turned at the pottery wheel, or of being hardened in the fire like clay. Even clay itself loses its tenacity by being baked in a gentle fire: a potter or a pipe-maker will in vain attempt to substitute the powder of potsherds, or of broken pipes, in the place of clay; these powders may be serviceable on some occasions, when mixed with clay, but they cannot, on any, supersede its use*.

The whitest clays are esteemed the purest, but even these, besides other impurities, generally contain a very
con-

* In the Mem. de l'Acad. des Scien. de Prusse, 1749, there are some experiments tending to prove, that the tenacity of clay is owing to some inflammable matter which is mixed with it, and which is easily consumed in the fire.

considerable portion of fine sand. I took 16 ounces of the finest pipe clay from Dorsetshire, and by repeatedly washing it in large quantities of water, and pouring off the turbid water, I collected a sandy sediment, amounting, when well dried, to three ounces. I have no doubt that this clay contained a much greater proportion of sand, than what I had been able to collect; for the white particles which had been suspended in the water, certainly consisted in part of a sand of a finer grain, than what had settled to the bottom, for they were very sensibly gritty between the teeth. It may easily be conceived, that in washing clays, the finest part of the sand contained in them will remain suspended in the water, and that on this account, the

sediment collected at the bottom of the vessel, in which the operation is performed, will not give the true proportion of the sand which enters into their composition. In confirmation of this idea, we have been instructed by the experiments of a very able chemist, to consider fine white clays, as consisting of about 3 parts in 8 of true argillaceous earth, and of about 5 parts in 8 of sand, or earth, resembling powdered flints*. All sorts of earthen wares from the coarsest pots to the finest pieces of either Asiatic or European porcelane, consist either wholly or principally

* M. Marggraf's Opus. Chy. Vol. II. p. 171.—Is it possible, by any artificial or natural comminution of its parts, to reduce the sand found in clay into a true argillaceous earth?

cipally of clay. There are a great many sorts of clay which differ from each other in colour, in tenacity, in the degree of contraction which they suffer in being burned, in their power of resisting the action of fire without being melted, and in many other properties; and hence we need be at no pains to prove, that the properties of earthen wares must be very various, according to the properties of the clays from which they are formed; and this variety becomes still greater, when we take into consideration the ingredients which are purposely mixed with the natural clays.

The *flint* or *white-stone* ware is made in Staffordshire, and other places, in the following manner.—Tobacco-pipe clay, which they have

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from

from Dorsetshire, is beat much in water; by this process the finer parts of the clay remain suspended in the water, whilst the coarser sand and other impurities fall to the bottom. The thick liquid, consisting of water and the finer parts of the clay, is further purified by being passed through hair and lawn sieves of different degrees of fineness: the clay is then sufficiently prepared to be mixed with powdered flint, the other ingredient in the stone ware. They use annually in Staffordshire about 5000 tons of flint, which they have from Hull. They have a tradition concerning the first introduction of flint into their potteries, which is briefly this:—A Staffordshire potter, about 80 years ago, in travelling to London, met at an inn upon the
road

road with an hostler, who undertook to cure a disorder in his horse's eye. The hostler took a flint stone, and having calcined it for a sufficient length of time in a hot fire, it became very white; he pounded it into a fine powder, and blew some of it into the eye of the animal: the potter took the hint, conceiving that as flints could be calcined and pounded into a fine white powder, they might be used in conjunction with clay to make a whiter ware than the clay would do alone. He amassed large quantities of flints, burned and pounded them in secret, and found the event answerable to his expectation. The discovery soon became general, and many lives were lost from the powder of the flint being inhaled by the men employed

in pounding it: horses were afterwards used for the same purpose, and for some time past they have been accustomed to grind their flint*. If the flints are pounded, or ground by instruments of iron, the powder is not so good as it ought to be, for the particles of the metal, which are abraded during the operation, being mixed with the powder, give the ware, when burned, a bad colour.

They formerly were accustomed to grind their flints with *Moorstone*, or *Granite*; but of late years a large bed of *Chert* (a species of flint) has been

* I suspect the date assigned by this tradition to the potter's discovery, for the grinding of flints is incidentally mentioned as practised at *Brosely* in the year 1697.—Phil. Trans. No. 228.

been discovered near *Bakewell* in *Derbyshire*, and the *Staffordshire* and *Yorkshire* potters prefer it to *Moorstone* for grinding their flints: it is very hard, and being itself of the nature of flint, the parts of it which are worn off and mixed with the flints in grinding, do not vitiate the quality of the flint powder. It is sold at the quarries for 8s. a ton, of which the *Duke of Rutland*, as lord of the soil, has 5s. and the workmen the other 3s. for raising it. It is reckoned that they annually raise between four and five hundred tons, besides the smaller pieces, which are thrown by as refuse; but which might be calcined upon the spot instead of flint, and being ground there, might answer the purpose of ground flint; though as coals are

comparatively dear at *Bakewell*, and as there is no navigation from thence into Staffordshire, I am not certain whether the ground *Chert* could be afforded to the potters at an easier rate than they can prepare their flint. However, *Chert* is very commonly to be met with in other parts as well as at *Bakewell*, though not, perhaps, in such large quantities, and therefore the hint of using calcined *Chert*, as a substitute for calcined flint, may be of service to those who are better situated with respect to fuel and water carriage, than they are at *Bakewell*.

When the flints have been properly calcined and ground, they are sifted in water till the water is, as near as may be, of the same thickness as that in which the clay is suspended;

pended; then the liquid clay and flints are mixed together in various proportions, for various wares, and left to set; the mixture is then dried in a kiln, and being afterwards beaten to a proper temper, it becomes fit for being formed at the wheel, into dishes, plates, bowls, &c. When this ware is to be put into the furnace to be baked, the several pieces of it are placed in cases, made of clay, called *Seggars*, which are piled upon one another, in the dome of the furnace; a fire is then lighted, and when the ware is brought to a proper temper, which happens in about 48 hours, it is glazed by common salt. The salt is thrown into the furnace (through holes in the upper part of it), by the heat of which it is instantly converted into
 a thick

a thick vapour, which circulating through the furnace, enters every Seggar through holes made in its side (the top being covered, to prevent the salt from falling upon the ware), and attaching itself to the surface of the ware, it forms that vitreous coat upon the surface which is called its *glaze*.

This very curious method of glazing earthen ware, by the vapour of common salt, was introduced into England from Holland, at least it was introduced from thence into Staffordshire, about 80 years ago, by two Dutchmen. An old man informed the person from whom I had the account, that he remembered, when he was a boy, running with others to help to extinguish what from the smoke they apprehended

to

to be a fire in the pottery where the Dutchmen were working, but that their entrance was opposed by the proprietors of the pottery, who were unwilling that the cause of the smoke, which was the common salt they were using in glazing their ware, should be generally known.

The *Yellow* or *Queen's ware*, is made of the same materials as the *flint* ware, but the proportion, in which the materials are mixed, is not the same, nor is the ware glazed in the same way. The flint ware is generally made of 4 measures of liquid flint, and of 18 of liquid clay; the yellow ware has a greater proportion of clay in it; in some manufactories they mix 20, and in others 24 measures of clay with 4 of flint. These proportions, if estimated by the

weight of the materials, would probably give for the flint ware, about 3 hundred weight of clay to 1 hundred weight of flint, and for the yellow ware somewhat more clay. The proportion, however, for both sorts of ware, depends very much upon the nature of the clay, which is very variable even in the same pit: hence they cannot be certain of the exact quantity of flint, which they ought to mix with the clay, till they have made some trial of the quality of the clay by burning a kiln of the ware. If there is too much flint mixed with the clay, the ware, when exposed to the air after burning, is apt to crack; and if there is too little, the ware will not receive the proper glaze from the circulation of the salt vapour. This glaze, even when it is
 most

most perfect, is an appearance less beautiful than the glaze on the yellow ware. This yellow glaze is made by mixing together in water, till it becomes as thick as cream, 112 pounds of white lead, 24 pounds of ground flint, and 6 pounds of ground flint glass. Some manufacturers leave out the glass, and mix only 80 pounds of white lead with 20 pounds of ground flint, and others doubtless observe different rules, of which it is very difficult to obtain an account. The ware, before it is glazed, is baked in the fire, by this means it acquires a property of strongly imbibing moisture (we perceive something of this in the force with which a new pipe sticks to the lips, though the pipe has received a kind of glaze by being rubbed with bees wax after
being

being baked), it is therefore dipped in the liquid glaze and suddenly taken out, the glaze is imbibed into its pores, and the ware presently becomes dry: it is then exposed a second time to the fire, by which means the glaze, which it had imbibed, is melted, and a thin glassy coat is formed upon its surface: the colour of this coat is more or less yellow, according as a greater or less proportion of lead has been used. The lead is principally instrumental in producing the glaze, as well as in giving it the yellow colour; for lead, of all the substances hitherto known, has the greatest power of promoting the vitrification of the substances with which it is mixed. The flint serves to give a consistency to the lead during the time of its vitrification,

tion, and to hinder it from becoming too fluid, and running down the sides of the ware, and thereby leaving them unglazed. The yellowish colour, which lead gives when vitrified with flints, may be wholly changed by very small additions of other mineral substances; thus, to give one instance, the beautiful *black glaze*, which is fixed on one sort of the ware made at *Nottingham*, is composed of 21 parts by weight of white lead, of 5 of powdered flints, and of 3 of an earthy, or metallic mineral called *Manganese*.

The powder into which calcined flints are ground, is whiter than common sand, and of a finer grain; and hence it constitutes, when mixed with clay, a species of earthen ware, superior to that in which sand is used

as

as an ingredient; the coarse *stone ware* made at *Bristol*, is composed of tobacco-pipe clay and sand, and is glazed by the vapour of salt, like the Staffordshire flint ware, but it is far inferior to it in beauty. As our flint ware is superior to the stone ware here mentioned, because it is made of materials, which, though of the same kind, are of a finer quality, than those which enter into the composition of stone ware; so is it inferior to all the sorts of porcelain in whiteness and transparency; because powdered flints and tobacco-pipe clay, are neither of them so white and pure as the clays and flints of which all porcelanes are made. According to this notion, the only difference between porcelanes and many sorts of earthen ware, consists in the fineness and

and proportion of the ingredients; and these causes joined to the different degrees of heat employed in baking different porcelanes, are abundantly sufficient to account for all the varieties observable in the grain, colour, hardness, and transparency, of different sorts of china.

We are told that the component parts of oriental porcelane, “are (1) a *vitrescent* stony substance, reduced to an impalpable powder, *Petunse*. (2) An *unvitrifiable* unctuous clay, reduced to an impalpable powder also, *Kaolin*. These are thoroughly mixed, the latter in as small proportion as possible, and then moulded and baked. (3) A varnish composed of the finest particles of a soapy earth, dissolved in water to the consistence of a cream, in which,

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when dry, the pieces are dipped before they are baked *." The Chinese *Petunse* differs from powdered flints, in being fusible in a strong degree of heat, whereas flints are not fusible in a fire sufficient for the baking of porcelane, unless they are mixed with some heterogeneous matter; and this property of the *Petunse* probably gives to china, a degree of transparency not observable in our flint ware; for the vitrifiable *Petunse*, when mixed with the unvitriifiable clay, may communicate a degree of vitreousness to the compound.

The moorstone or *granite* found in *Cornwall* is thought to resemble the Chinese *Petunse*; and the *Soap-rock*, which is plentifully met with at the *Land's End*, is esteemed a species of
Kaolin,

* Campbell's Surv. of Brit. Vol. II. p. 18.

Kaolin, and is much sought after by the makers of porcelane. The granite is looked upon by mineralogists as a vitrifiable stone ; at least, as to the greatest part of it *, and there may, probably, be discovered other stones which possess the same property. The lead mines in Derbyshire abound in two kinds of spar, which are very different from each other in figure (where the figure is discernible), in weight, and in the change which they undergo from the action of fire. The figure of one of the kinds of spar is that of a *lozenge* or *rhomb* ; the figure of the other is that of a *die* or *cube* : a cubic foot of the *rhomb*-

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boidal

* ——— Exposé au feu, il s'y vitrifie, à l'exception du *mica*, et du ciment qui souffrent la même violence du feu sans en être altéré.—
Miner. par M. Val. de Bomare, Vol. I. p.
275.

boidal spar weighs 2700 ounces; a cubic foot of the *cubical* spar weighs 3219 ounces: the *rhomboidal* spar, in being calcined in a strong fire, loses near 18 parts in 40 of its weight, and is changed into quicklime; the *cubical* spar in the same degree of heat loses about 1 part in 40 of its weight, and is not converted into quicklime: the *cubical* spar may be melted in a degree of heat, in which the *rhomboidal* spar remains unmelted; and from this property, the *cubical* spar might, probably, be used with advantage by the porcelane manufacturers. Some mines, as those near *Critch* in *Derbyshire*, yield no kind of spar but the *cubical*; whilst others yield only the *rhomboidal*; and some yield both: I have seen a narrow crack in a limestone rock,
coated

coated on one side with the cubical, and on the other with the rhomboidal spar.

Having fallen into the mention of spars, it may just be observed, that *Blue-John*, which has, of late years, been fabricated into vases, and other ornamental figures, is of the same quality as the cubical spar, with respect to its fusibility in the fire; it loses, moreover, its colour, and becomes white in a moderate heat: the weight of a cubic foot of the bluest kind is 3180 ounces, and that of a cubic foot of the least blue is 3140 ounces. This substance was first discovered (or more properly speaking, it first began to be applied to some use), about 16 years ago, at one of the oldest lead mines in *Derbyshire*, called the *Odin* mine (probably from

its being dedicated to *Odin*, the great God of the northern nations), at the foot of a high mountain called *Mam Tor* near *Castleton*. Spars tintured with the *amethyst* colour have been discovered in other mines; there is great plenty of what they call the *chocolate* coloured spar, in a mine at *Critch* (a few miles from *Matlock*), where I saw the last year, a piece of oak, which had stood long in the water of that mine, tinged with a deep purple colour; but the greatest quantity of *Blue-John* is still raised at *Castleton*; the largest pieces are sold for 9 pounds a ton, the middle-sized for 6 pounds, and the least for fifty shillings.—But to return to the consideration of porcelane.

Several European nations, in particular the *Germans*, the *English*, the *French*,

French, and the *Italians*, have, since the beginning of the present century, applied themselves with great industry and ingenuity, to the making of porcelane, and they have all of them arrived at great perfection in the art; though none of the European porcelanes, unless, perhaps, we except the *Dresden*, can yet be said to equal, both in strength and beauty, the porcelanes which are imported from *China* and *Japan*. The *Dresden*, and the German porcelanes in general, are as unvitriifiable as the Asiatic; while most of the others which are made in Europe, may be vitrified by a longer continuation of the heat, in which they are baked. The being or the not being convertible into glass in a strong fire, is one of the principal criterions by which

connoisseurs judge of the goodness of porcelane, that being esteemed the best which is the least fusible. Porcelane being seldom exposed to a degree of heat, greater than that of boiling water, it seems to be an odd method of judging of its worth, by inquiring whether it is capable of sustaining, unaltered in its form, a degree of heat sufficient to convert many other substances into glass; but probably that sort of it is the most hard, and tough, and best capable of bearing the sudden transitions from heat to cold, which is baked with the strongest heat; and, if this be true, then there is a good reason for esteeming that china to be the best, which is the most unfusible, inasmuch as it has, probably, undergone a stronger fire in being baked than

than the more fusible kinds could support.

There is some reason for thinking, that the strength of porcelane has some dependence on its weight, for the more closely its parts are compacted together, the more forcibly, other circumstances being the same, will they resist the impulse of a stroke, tending to disunite them. I have estimated the relative weights of most of our English porcelanes; but I forbear mentioning particulars, as I should be sorry to say any thing which might have the most distant tendency to injure any individual; especially as the great price of labour in this country, and, indeed, in all parts of Europe, compared with its price in Asia, must ever render the engaging in a porcelane manufactory
a ha-

a hazardous undertaking whilst the importation of Asiatic porcelane is allowed. The best mode of encouraging the European manufactories of porcelane, would be the imposition of a heavy duty on that which is brought from Asia. It is, I believe, generally acknowledged, that the *yellow ware*, is far more brittle than the *flint ware*; the relative weights of a cubic foot of these wares and of East India china, were

East India china	2346	} ounces avoird.
Flint ware - -	2188	
Yellow ware - -	1988	

Now supposing a plate of the common yellow or Queen's ware (for there are very different sorts of it) to weigh 12 ounces; then will a plate of the flint ware of exactly the same

same size and thickness weigh $13\frac{2}{5}$ ounces; and an equal plate of china will weigh $14\frac{1}{6}$ ounces; and hence we need not wonder at the great fragility of the common yellow ware, when compared either with china or flint ware. The coarse Bristol stoneware has nearly the same weight as china, a cubic foot of it weighing 2340 ounces.

The precise meaning of the term *marle* is not yet fully fixed; it is most generally used to denote an earthy or stony substance, consisting principally of *clay* and *calcareous* earth, and falling into powder by exposure to the air. There are several solid strata of stones, such as the Derbyshire *shale* and *toadstone*, which moulder into powder by exposure to the air, and yet they are not esteemed marles,

marles, because they do not contain any calcareous earth; there are also limestones which contain portions of clay, and clays which contain portions of limestone, but which not falling into powder by the influence of the air, are not classed amongst the marles: and hence these two properties, of containing calcareous earth, and of falling into powder when exposed to the air, may be esteemed characteristic of marles; and they are, perhaps, the characteristics which are most to be relied on, for as to colour and consistency, marles cannot by them alone be distinguished from several other bodies.

As the use of marle in agriculture, depends in some sort of soils upon the quantity of calcareous earth
which

which it contains, and in others upon the clay which enters into its composition, some readers will wish to be acquainted with a general method of ascertaining the exact proportion of clay and calcareous earth, contained in any particular kind of marle.

Take an ounce of the proposed marle, previously reduced into powder, and well dried; pour upon the marle a diluted acid of sea salt; an effervescence will ensue; this effervescence arises from the action of the acid on the calcareous earth, for the acid has no such action on pure clay, nor even on clay and sand, as may be seen by pouring a little of it on pipe-clay; when so much acid has been added to the marle that no further effervescence is observed, we
may

may conclude that all the calcareous earth contained in the marle is now dissolved in the acid: put the whole into a filter; the calcareous earth being dissolved in the acid will pass through the filter, whilst the clay will remain upon the filter: wash the clay, and the filtering paper, by pouring upon them hot water till they are freed from all saline particles; the clay being afterwards dried, as the ounce of marle had been, will shew, by its loss of weight, the quantity of calcareous earth which the marle contained. As to the matter which remains upon the filter, and which has been called clay, it may chance either to be pure clay, or a mixture of clay and sand; if it is the latter, the quantity of sand
may

may be known by washing it and collecting the sediment.

This method of examining how much calcareous earth is contained in any species of marle, may be usefully adopted also when the clay or marle is to be applied to the making of brick. For if the quantity of calcareous earth is large, the marle in being burned will rather form lime than brick, or the brick at least will soon moulder in the air, in consequence of the calcareous earth falling into a powder like lime.— The marle dug out of the same pit is often very different in its properties, some parts of it containing so much calcareous earth, that they may with advantage be burned into lime; whilst other portions of it may be made into good brick. I will

Illustrate what has been said concerning the analysis of marle, by an instance.

We have a stratum of lead-coloured clay, a little beyond Magdalen College, on the road to Ely, which burns to a whitish brick: I took four ounces of this clay, moist as it was dug out of a pit, ten or twelve feet deep; by being dried on a hot fire-shovel till no more vapour appeared to rise from it, the weight was reduced to three ounces. These three ounces, or 60 pennyweights, were put into a quantity of diluted acid of salt, till no more effervescence was observed, the mixture was filtered, and what remained upon the filter, being dried, weighed 46 pennyweights, the quantity of calcareous earth amounting to 14 parts in

in 60, or near $\frac{1}{4}$ of the weight of the clay when dried. What remained upon the filter was washed in much water, I obtained a sediment amounting to about 1 pennyweight, but it was not a sandy sediment, it resembled an earthy salt, resulting from an union of the acid of vitriol with calcareous earth, which is usually called *Selenites*; there was also separated, by washing, a quantity of greyish earth, which was chiefly iron.

The moulds, used in making bricks from this clay, are 10 inches in length, and 5 in breadth, and the bricks, when burned, usually measure 9 inches in length, and $4\frac{1}{2}$ in breadth, so that the clay shrinks about 1 inch in 10. But the degree of contraction, which clays undergo

in being burned, is very various, and it does not solely depend upon the purity of the clay ; for I have been informed by persons employed in making coarse earthen ware from simple clay, that the same clay just dug out of the earth, and put into the fire, will contract less, than when it has been some time exposed to the influence of the atmosphere ; for frost more perfectly divides its particles than any artificial process can do: the Chinese are said to let their clay remain exposed to the atmosphere 20 or 30 years, before they apply it to the making of porcelane: and the goodness of common tiles, and bricks, is much increased, by suffering the clay to lie mellowing for a year or two before it is used.

The

The clay here spoken of, though it does not contain so much calca-
reous earth, as to render it a proper
manure for stiff, loamy soils, yet it
might probably be used, with great
advantage, on those which are light
and sandy; inasmuch as by its clayey
part (for clay is greatly retentive of
humidity) it would contribute to
keep the ground from being depriv-
ed of its moisture, by the action of
the sun and wind during the height
of summer. The quantity of mois-
ture which is imbibed by the leaves
of vegetables from the atmosphere,
as well as that which is sucked in by
their roots, has a great dependence
on the moisture of the ground on
which they grow; for when the
ground is dry, the air incumbent
upon it will, comparatively speaking,

be dry also, and the vegetables which grow in that dry air, will lack a part of that moisture which is necessary to their well being, for whether *moisture* be itself the *food* of vegetables, or only the *vehicle* of food, it is indispensably necessary for the promotion of vegetation*.

From the consideration of marle we pass to that of *alabaster*, which is seldom found in beds, except in conjunction with marle. There is some confusion both in the philosophical and in the common acceptance of the term *alabaster*, I do not mean merely with respect to the colour and transparency of the substance, but with relation to its constituent parts. This confusion may
be

* Vegetabilia omnia a liquoribus omnino crescunt.—Newton.

be greatly removed, by admitting two sorts of alabaster, which are essentially different from each other, *calcareous* and *gypseous* alabaster: to which sort any particular specimen belongs may be determined by the easiest experiment. Dip a feather in the acid of sea salt, touch the specimen of alabaster with the wet feather, if an *effervescence* ensues, the alabaster is *calcareous*, it is of the nature of marble, and may be burned into lime; if no *effervescence* ensues, the alabaster is *gypseous*, it is of the nature of *Plaster-of-Paris*, and very different from every sort of marble. This substance is called in the north of England *alplaster*, being a corruption probably of alabaster, and it is also often called by the Latin appellation *gypsum*, especially by the

French. *Gypsum* was applied by the ancients to the very same purposes to which it is applied by us; they used it in architecture for the making of ceilings, medallions, and cornices; and even the name of the person, who first invented the method of taking off the impression of a man's face in gypsum, has been preserved by Pliny*.

There are some sorts of *alabaster* which differ so widely in weight, both from the finest kinds of plaster-stone, and of calcareous stone, that I know not how they can properly be

* *Ufus gypsi in albariis, figillis ædificiorum, et coronis gratissimus. Plin. Hist. Nat. L. xxxvi. f. 59.—Hominis autem imaginem gypso e facie ipsa primus omnium expressit Lyfistratus. Id. L. xxxv. f. 54.* where it is observed that the *cast* was improved by pouring wax into the gypsum mould.

be considered as being of the same nature with either of them. Mr. Cotes has fixed the weight of a cubic foot of alabaster at 1875 ounces*, and two other authors have represented it as weighing 1872 ounces†. I have tried several specimens of the finest Derbyshire plaster-stone, and find that a cubic foot of it weighs, at a medium, 2286 ounces; a cubic foot of the Derbyshire wattricle, which is a fine calcareous stone, resembling alabaster in colour and transparency, weighs 2720 ounces.

Two substances when combined together in different ways, or in different proportions, may constitute a great variety of bodies differing much

* Cotes's Hydros.

† Muffchenbroek—Wallerius.

much from each other in external appearance, and somewhat, probably, in their internal properties. We have an instance of this in the combination of the acid of vitriol with calcareous earth, for this combination constitutes a great many substances exceedingly different from each other in appearance. I will mention some of the most remarkable. (1) A solid substance not so hard nor so heavy as marble, nor so capable of receiving a fine polish, but consisting of finer particles, and having a greater degree of transparency — *Gypseous alabaster*. (2) A substance composed of larger particles than the preceding, and having a scaly or granulated texture — *Plaster-stone*. (3) A substance whose parts, instead of being flat or granulated,

lated, lie in longitudinal fibres, like a parcel of needles, or a skein of thread — *Striated gypsum*. (4) A pellucid substance consisting of a number of transparent plates of a lozenge-like form, found in great plenty and perfection at *Shotover-hill*, near Oxford — *Rhomboidal selenites*. (5) Some take the *lapis specularis* which the ancients used instead of glass, to have been composed, like all the preceding bodies, of the acid of vitriol and calcareous earth; whilst others look upon it as a species of *talc*, which differs from plaster-stone in this, that it does not, after being calcined and wetted with water, swell and concrete into a hard stony substance. This *lapis specularis* came into use at Rome in the age of *Seneca*;

neca *; it was soon after its introduction applied not only to lighten apartments, but to protect fruit trees from the severity of the weather †; and it is recorded to have been principally by its means, that the Emperor Tiberius was enabled to have cucumbers at his table during almost every month in the year ‡. I believe

* Quædam nostra demum prodiisse memoria scimus, ut *speculariorum* usum, perlucens testa, claram transmittentium lucem. Sen. E. p. 90.

† Pallida ne Cilicum timeant pomaria brumam,

Mordeat et tenerum fortior aura nemus:
Hibernis objecta notis *specularia* pueros
Admittunt soles, et sine fæce diem.

Mar. L. viii. epig. 14. et 68.

‡ Nihilo minus *specularibus* integri debent ut etiam frigoribus serenis diebus tuto producantur ad solem. Hac ratione fere toto anno Tiberio Cæsari *cucumis* præbebatur. Colum. L. xi. c. 3.

lieve it is still used in some countries in the place of glass, and we certainly know that it was so used in the time of *Agricola*, for he mentions two churches in Saxony which were lighted by it*.

If the *lapis specularis* was a kind of transparent *plaster-stone*, it must have been subject to one inconvenience, it could not have long stood the action of the weather: for *gypseous alabaster*, *plaster-stone*, *selenites*, and all other combinations of the *acid* of *vitriol* with *calcareous earth*, are soluble in water, either wholly or in a great degree. These substances require, indeed, a greater proportion of water to dissolve them, than any other saline substances do, but they are, nevertheless, soluble in water.

I took

* Agric. de Natura Fos. L. v. p. 257.

I took some very white plaster-stone, and pounded it into a fine powder; 1 pennyweight of this powder was put into a pail, containing 10 quarts of water; the powder was entirely dissolved in it; from hence we learn, that this kind of plaster-stone is wholly soluble in water; the water was pump water of 48 degrees of heat. I thought that this quantity of water was perfectly saturated with 4 pennyweights, or 96 grains of the powder, and hence it seems as if spring water, which is usually of the temperature of 48 degrees, would dissolve about one fourteen hundredth part of its weight of plaster-stone. There are great beds of plaster-stone in the environs of Paris, and the hardness of the well water of that city is thought to arise from the
par-

particles of plaster-stone which are dissolved in it.

Agricola esteemed the *lapis specularis* to have been a species of plaster-stone, and in speaking of it he remarks, that though it could bear, without being injured, the heat of summer and the cold of winter, yet, the largest masses of it were wasted by the rain*. I tied a lump of plaster-stone, weighing two ounces, to the end of a pair of scales, and kept it suspended in the middle of a pail of water for 48 hours, the water having been changed two or three times in the interval; at the end of
the

* Res *gypso* cognata *lapis specularis*—fert calores solis et hyemis frigora, sed inbrium adeo impatiens est, ut si vel magnæ ejus moles ipsis fuerint expositæ corrumpantur. Agric. de Nat. Foss. L. v. Ed. Bas. 1546.

the experiment, it appeared, that the plaster-stone had lost one thirtieth of its weight.

There are many places in England, where plaster-stone is gotten in great abundance, the principal of those which I have seen, are at *Chelaston*, a small village about four miles south from *Derby*, and at *Beacon-Hill* near *Newark*. They annually raise at Chelaston about 800 tons of plaster-stone, which is sold upon the spot for 5s. a ton. It is chiefly used for the making of floors in Derbyshire, Leicestershire, and Nottinghamshire : that which has a blueish cast is most esteemed for flooring ; the very white pieces are sold to the potters ; to the polishers of spar, who call it alabaster (though they get their best sort of alabaster from Staffordshire); and

to

to the plasterers. The plaster-stone before it is used, either for floors or ceilings, is calcined; it loses in that operation, from 4 to 6 hundred weight in a ton; the loss, however, in the same kind of stone, depends very much upon the degree of heat with which it is calcined. I calcined, in the same crucible, a piece of Derbyshire wattricle, a piece of fine grained plaster-stone, and a piece of the striated kind from Chelaston. The wattricle lost after the rate of 8 c. 3 q. 17 lb. in a ton; the plaster-stone lost after the rate of 12 c. 0 q. 3 lb. and the striated kind after that of 10 c. 0 q. 2 lb. in a ton. When the stone is calcined, those parts of it which are exposed to the greatest heat, are sometimes melted, and they frequently acquire a yellowish cast,

and emit a sulphureous exhalation, and are in both cases thrown aside as useless. The flooring made from the stones, which are become sulphureous by calcination, is apt to rise in blisters; this proceeds from the plaster-stone having lost a portion of the vitriolic acid, which enters into its composition, and being thereby changed into a species of lime. They calcine the stone usually at night, that they may be the better able to observe when it becomes red hot, in which state they judge it to have received heat enough. After calcination they reduce it to a powder, by threshing it with flails, or grinding it in a mill; and when it is become of a due fineness, they mix it with a proper quantity of water, and spread it to the required thickness upon reeds,

reeds, where it immediately concretes into a solid floor; 30 hundred weight of the crude stone will, when calcined, make 20 square yards of flooring of $2\frac{1}{2}$ inches in thickness. For preparing the stone, and shooting the floor, the Derbyshire masons charge 9d. a square yard; hence 20 square yards of plaster flooring, including the price of the stone at the pits, will cost 1l. 2s 6d.—The additional expence must be various, it depending upon the price of the conveyance of the crude stone, from the place where it is dug, to the place where it is used. Plaster-stone, however, is found in so many parts of the kingdom, and the inland navigations are become so commodious, that plaster flooring might be introduced into many countries with a

considerable saving of expence; a circumstance especially to be attended to in the erection of public infirmaries, and houses of industry.

They have sawn out of the quarry at Chelaston, square blocks of a yard in breadth and thickness, and of two yards in length; and blocks of still greater dimensions have been raised at a place called *Red-bills*, in the county of Nottingham, about four miles from Chelaston. The stone from the *red-bills* is not so good for flooring, as that at Chelaston; it is, however, a very beautiful stone, *Lord Scarsdale* having gotten from thence those superb columns which adorn his hall at *Kedleston*. These columns are made of different blocks, from 2 or 3, to 6 or 8 feet in height, which are so artfully cemented together, that they

they may be taken for one piece. The blocks are raised out of the quarry, by being sawn to the proper length on each side, and to the depth requisite for the thickness of the column, the block still adhering by its lower surface, to the quarry, is broken off from thence by being raised on each side with levers. It is afterwards rounded into the proper cylindric form by the mallet and chisel, and polished by being rubbed with various kinds of stones, then with emery, and last of all with putty. If the veins of the separate blocks which are to compose the shaft of an alabaster column, of the kind we are speaking of, do not happen to suit each other; in order to make the juncture less discernible, and to give a greater appearance

of consistence to the whole column, small pieces are here and there cut out of the separate blocks, and others of a different colour inserted, and cemented by a mixture of rosin and bees-wax, tinged green, red, brown, yellow, according to the nature of the piece to be inserted.

Alabaster columns, though they are much easier to be wrought than marble, and when finely polished look very well, yet, I apprehend, their polish must be injured by a circumstance which does not affect either *marble* or *calcareous alabaster*. The atmosphere is always much charged with humidity, upon the breaking up of a frost, and in other states of the weather, so much water is discharged from the air, that marble,
wain-

wainscot and other substances upon which it settles, are said to sweat.— Now the water which thus settles on a *gypseous alabaster* column, will dissolve part of the substance of the column, and as some parts of the alabaster, are more soluble than others, the uniformity of its surface will be injured; and the part, moreover, of the alabaster which has been dissolved, will, upon the evaporation of the water, either not adhere at all to the column, or it will adhere in such a way, as to render the polish less glossy. But whether this account of the matter be admitted or not, the fact, I believe, of the polish of gypseous alabaster being injured by moist weather, is not to be denied. The alabaster columns in the Egyptian Hall at *Holkam*, were dug from the

quarries in Staffordshire, and the late Lord *Leicester* was at the trouble of contriving means to keep them dry in moist weather, lest their polish should be impaired by the action of the moisture.

They annually raise about 2000 tons of plaster-stone at the pits near Newark; it is sold on the spot at 5s. 6d. and at Gainsborough at 8s. 6d. a ton, from whence it is sent to London and various other places.

It having been said, that plaster-stone is a saline substance resulting from an union of the acid of vitriol with a calcareous earth, the reader may expect some proof of the assertion. — Boil together pot-ash and plaster-stone, and you will obtain the same kind of salt, which would arise from uniting the acid of vitriol
with

with pot-ash; and thence we conclude, that the *acid of vitriol* is one of the component parts of plaster-stone: that *calcareous earth* is the other, is evident from this consideration, that the earth, which remains after the acid of vitriol has been separated from the plaster-stone, effervesces with acids, and may be burned into lime.

Having said so much concerning gypseous alabaſter, which is an earthy salt resulting from an union of the *acid of vitriol* with a *calcareous* earth; it may not be improper to add a word or two concerning *alum*, which is an earthy salt, composed of the *acid of vitriol* and an *argillaceous* earth. The acid of vitriol when united with any earth, may be separated therefrom by a fixed alkali; and

if we pour into a solution of alum any fixed alkali, the earth of alum will be precipitated, and we shall obtain a salt, of the same kind as would result from a direct combination of that alkali with the acid of vitriol; and thence it is inferred, that the *acid of vitriol* is one of the component parts of alum: upon examining the earth, which is precipitated by the alkali, it will be found to be very white, and very tenacious, and to be capable of being hardened in the fire; in short, it is one of the purest clays in nature: and thence it is concluded that an *argillaceous* earth is the other component part of alum. The constituent parts of alum may also be proved by its artificial composition, for though the vitriolic acid, when poured upon pipe-clay, does

does not seem to act upon it, yet if it be boiled with it, a solution of the clay in the acid takes place, and an alum may be obtained by slowly evaporating the solution.

Being one day engaged in evaporating something or other, from a faucer made of the Staffordshire yellow ware, I was surpris'd to see a white substance bubbling through a crack in the faucer; upon tasting it I found it to be a salt; I collected a sufficient quantity of it, and when it was dissolved and crystallized, it appeared to be a perfect alum. The fire was a very hot one, and it was made of coal cinders; the faucer was placed on the bar of the grate, and the alum, I conceive, was formed from the *sulphureous acid* of the cinders uniting itself with the *clay*, which
enters

enters into the composition of the yellow ware. I have been informed by a very intelligent person, that the vapour which, in some places, escapes from the coal-pits which are on fire in Staffordshire, forms an alum wherever it meets with an argillaceous earth. This is very conformable to the manner of making alum on the *Solfatara* near Naples, where they place little heaps of *argillaceous* earths, or stones, over the crevices from which the sulphureous vapour issues, in order that they may collect a greater quantity of alum*.

In England we make alum from a black slaty substance, called *shale*, this substance is a clay, hardened into a stony consistence, and so much
im-

* Lett. sur la Minera. par M. Ferber, French Transl. p. 261.

impregnated with bitumen, that it burns somewhat like coal. We have seen, that coal emits, when it is in the state of a red-hot cinder, a sulphureous acid: many other bitumens, probably, in the same state emit the same acid, and the acid which is emitted from shale during its calcination, uniting itself to the argillaceous earth of the shale, forms alum. About 120 tons of calcined shale, will make 1 ton of alum. The shale, after being calcined, is steeped in water, by which means the alum, which is formed during the calcination of the shale, is dissolved; this dissolved alum undergoes various operations, before it is formed into the alum of the shops. The greatest alum works, and, I believe the only ones which now subsist in the kingdom,

dom, are at *Whitby*; a few years ago there were some in Lancashire; and alum might be made in many other parts; but *Whitby* is so conveniently situated for coal and water carriage, that alum can be there afforded at a cheaper rate than in most other places, and it costs even there 9 or 10l. a ton making.

ESSAY VIII.

OF PIT-COAL.

I Took 96 ounces of *Newcastle* coal, and putting them into an earthen retort, distilled them with a fire gradually augmented till nothing more could be obtained from them. During the distillation there was frequent occasion to give vent to an elastic vapour, which would otherwise have burst the vessels employed in the operation. The weights of
the

the liquid found in the receiver, and of the residuum remaining in the retort, after the distillation was finished, were accurately taken, and are expressed in the following table.

Weight of *Newcastle* pit-coal distilled - - - 96 ounces

Weights of the products.	Liquid -	12	} ounces.
	Residuum -	56	
	Loss of weight	28	
		<hr/> 96	

Professor *Newmann* analysed, by distillation, the best sort of the pit-coal found at *Halle*, in *Germany*. He used only 48 ounces in his analysis, but I have expressed the result of his operation, upon the supposition of his having used twice as much, or 96 ounces*.

Weight

* *Newmann's Chem.* by *Lewis*, p. 245.

Weight of the *Halle* pit-coal distilled - - 96 ounces

Weights of the products.	{	Liquid -	12	} ounces.
		Residuum -	83 $\frac{3}{4}$	
		Loss of weight	0 $\frac{1}{4}$	
			<hr/> 96 <hr/>	

Dr. *Venel*, of Montpellier, analysed, by distillation, 64 ounces of the pit-coal of *Alais* in *Languedoc*; supposing that instead of 64 he had used 96 ounces, the result of his analysis would have been expressed by the following numbers* :

Weight

* Instructions sur l'Usage de la Houille.
A. Avignon, 1775, p. 45.

(320)

Weight of *Alais* pit-coal distilled - - - 96 ounces.

Weights of the products.	{	Liquid -	10½ +	} ounces.
		Residuum -	84	
		Loss of weight	1½ —	
		<hr/> 96		

M. *Sage*, of the Academy of Sciences at Paris, says that he has distilled various specimens of pit-coal, taken from different places, and that they generally yielded 2 ounces of liquid from 16 ounces of coal*, that is 12 ounces from 96; which is the same proportion as in the analysis of the Newcastle and Halle pit-coal. He does not mention the weights of the residuums, so that the

* *Elémens de Mineralogie.* A Paris, 1778, tome prem. p. 94.

the losses of weight, in his distillations, cannot be ascertained.

These several analyses correspond so nearly, with respect to the quantity of liquid procurable from different sorts of coal, that they very much confirm one another; and make it probable, that we shall not be far from the truth in generally asserting, that pit-coal contains one-eighth part of its weight of liquid.

With respect to the nature of the liquid, it may be observed, that when poured out of the receiver, it is seen to consist of three different substances: (1) The middle part is an acid watery fluid, of a reddish colour, it seems as if it was loaded with oil, and it smells of volatile alkali: (2) On the surface of this watery fluid there floats a small por-

tion of oil, more or less liquid and transparent, according as the heat used in conducting the distillation has been less or greater: (3) At the bottom there is found a black thick tenacious oil, very much resembling tar. The two oils together amounted in the distillation of the Newcastle coal to four ounces, or one-third of the weight of the whole liquid; in the analysis of the Halle and Alais coals, as well as in the experiments of M. Sage, the two different sorts of oils were observable, but they bore a greater proportion to the whole of the liquid, than in the Newcastle coal, amounting to one half of the weight of the liquid. This difference makes me suspect that I committed some error, in estimating the quantity of oil obtained from

from the distillation of Newcastle coal. It is probable, however, that the quantity of oil separable from the same kind of coal, may be influenced, in some degree, by the manner of performing the operation; and there is, moreover, some reason to believe, that in different kinds of coal the quantities of oil may be very various; as we observe them to differ from each other both in their proneness to catch fire, and in their ability to support it: though it must be owned, that both these effects may as consistently be explained, from the difference of the manner in which the oil may be combined with the other principles of the coal, as from the difference of its quantity.

The correspondence, with respect to the quantity of liquid obtained by the several distillations of English, German and French pit-coal, would induce one to suppose that the experiments had been respectively made with great accuracy; but the great disparity, as to the quantity of the residues remaining after the extraction of the liquid, seems to indicate the contrary; for it is greater, I apprehend, than can be accounted for from the different natures of the coals. The German and French analyses corroborate each other, and the reader may thence reasonably be disposed to question the truth of mine. He will permit me, however, to produce a testimony in its support, and which is, perhaps, the more to be

be depended on, as I was not aware of it when the analysis was made.

Dr. Hales*, by distilling 158 grains of Newcastle coal, obtained 51 grains of *air*. From 96 ounces he would, according to the same proportion, have obtained 30 ounces of air; now the difference between 28 ounces of some sort of matter or other which was lost during my distillation of 96 ounces of coal, and 30 ounces of air, which might have been obtained from the same quantity of coal by Dr. Hales' method, is so small, that it may easily be accounted for from the different modes of operating, or from a slight difference in the qualities of the coals. Many naturalists have thought that pit-coal has been

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* Vegetab. Stat.

produced from vegetables, and especially from forests of resinous woods, which have been buried in the bowels of the earth; without entering into all the reasons on which this opinion is founded, I will lay before the reader an account of the products obtainable from different woods by distillation.

The woods which I distilled were heart of *Oak*, *Box*, *Mahogany*, and *Sallow*. They were all dry and old, and were cut into small pieces, about half an inch square, before they were put into the earthen retort. The annexed table shews, at one view, the result of the respective distillations.

Heart

Heart of Oak.		Box.	Mah.	Sall.
Weight distilled, 96 oz.		96	96	96
Liquid	- - 37 $\frac{1}{4}$	61 $\frac{1}{2}$	33 $\frac{1}{2}$	48
Residuum	- - 30	26 $\frac{1}{2}$	27 $\frac{1}{2}$	20 $\frac{1}{2}$
Loss of weight	- 28 $\frac{3}{4}$	8	55	27 $\frac{1}{2}$
	96	96	96	96

The liquids separable from woods by distillation, consist partly of oil, but principally of water impregnated with an acid, from which also a volatile alkali may be disengaged. The oil varies in quantity according to the nature of the wood, the hardest woods, and the hardest parts of the same wood abounding most in oil; thus both oak and box contained, in the same weight of the wood, more oil than fallow did. That part of the oil which is first separated from the wood is so light as to float

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upon

upon water, and of a yellowish colour; its quantity, however, is but small, compared with that of the thick, black, heavy oil, which follows it. It appears from this account, that the quality of the liquid separable from wood by distillation, is wholly the same with that of the liquid separable from pit-coal by the same means.

The matter which is lost during the distillation of both wood and pit-coal has been called *air*, and it certainly has one, at least, of the most distinguishing properties of *air* — *permanent elasticity*, for bladders may be inflated with it as with common air. It does not begin to be separated from either wood or coal till the lighter of the two oils begins to appear; it then rushes out with great

great violence, and unless a proper vent be given to it, the strongest vessels will be burst by it.

In distilling heart of oak, during the course of chemical lectures which I read in the university of Cambridge, in the year 1767, I remarked to the audience, that the air which issued with great violence from the oak was inflammable, not only at its first exit from the distilling vessel, but after it had been made to pass through two high bended glass tubes, and three large vessels of water. I at first supposed the inflammability to proceed from some oily particles which had accompanied the air, and which I thought would soon be condensed by the cold, though they had not been

been condensed in passing through the water; but upon repeating the experiment, and collecting the air in bladders, I found that it retained its inflammability a long time, and burned like the air, separable from some metals by solution in acids.

From the researches which have been lately made on this subject, it is now believed, that this kind of air may be separated from all vegetable, animal, and inflammable mineral substances by distillation; and the common burning of wood, coal, paper, pitch, oil, and other combustible bodies, is attributed to this air, which being separated from the body by the heat, and inflamed by the contact of the fire, continues to burn as long as the body continues
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to afford a proper supply of it. *Inflammable air*, considered in this view, bears a great resemblance to what the chemists have hitherto understood by their *phlogiston*, or food of fire.

Distillation is not the only means of separating *inflammable air*, from vegetable and animal substances, it is found to be produced by *putrefaction*. Stagnant waters, whose bottoms are covered with putrefying vegetables, yield an inflammable air; the *Thames* water, in becoming putrid, yields an inflammable air: and the same observation may, probably, be true of other river waters which are subject to putrefaction. An inflammable air has been observed also in swampy grounds, in cellars, and in privies. There are many instances recorded,

corded, of a vapour issuing from the stomachs of dead persons, which took fire on the approach of a candle* the matter producing that vapour could not, probably, become putrid enough in the stomach, to generate an inflammable vapour, whilst the persons were alive; for Van Helmont has remarked, that the air discharged from the stomach by eructation, is not inflammable, but that it becomes so in the lower intestines†.

From

* Collect. Acad. Tom. III. Part Etrang. p. 16.

† Ruētus sive flatus originalis in *stomacho*, prout et flatus Ileī extinguant flammam candelæ. *Stercoreus* autem flatus, qui in ultimis formatur intestinis, atque per anum erumpit, transmissus, per flammam candelæ transvolando accenditur, ac flammam diversicorem, iridis instar exprimit. Van Helmont, Oper. p. 405.

From heart of oak moderately dried, Dr. Hales got one third of the weight of the oak of the air here spoken of; this proportion sufficiently agrees with the quantity which was lost during the forementioned distillation of oak.

A cubic foot of dry *box-wood* weighs, according to Mr. Cotes' table of specific gravities, 1030 ounces; hence, supposing that 96 ounces of such wood had only given 61 ounces of liquid, it may appear by an easy calculation, that a cubic foot of dry *box-wood* contains above 5 gallons of liquid; supposing the liquid to be no heavier than water; and if we admit the oil and the acid, when concentrated, to amount to two quarts, the other 18 quarts may be looked upon as pure water; nay, the quantity

tity of water may be considered as amounting to almost the whole of the liquid, since both acids and oils principally consist of water.

A cubic foot of *fallow* weighs, according to Muschenbroek, 585 ounces, and supposing that 96 ounces of such wood would yield by distillation 48 ounces of liquid, then a cubic foot would contain about 9 quarts of liquid, which is not half so much as an equal bulk of box-wood contains.

I put the matter in these different lights, in order to excite those who have leisure to make similar inquiries, for it is undoubtedly a very wonderful thing, that such large quantities of *water*, and *air*, should be combined with the *earth* of wood, by such a peculiar bond of union as

to remain for ages without losing any of their distinguishing properties. And here I am sensible is great room for many physical investigations. — Are the densest woods the most abundant in air and water? Is the air *generated* by the process of distillation, or only *disengaged* from the wood, into the composition of which it had entered, together with water, by *vegetation*? Have the *inflammable airs*, separable from different woods by distillation, the same specific gravity and the same degree of inflammability? Or is the inflammability influenced by the nature of the *oil* contained in the wood? How long will a given quantity of air retain its inflammability? Does it lose it in consequence of the *precipitation of some oily particles*, which are dissolved

solved in it, when it is first distilled?
 As no particle of matter can be annihilated, what becomes of the inflammable air, after it has been inflamed? Is it reduced to an unelastic *earth*, or does it still exist under the form of an unflammable elastic *fluid*? Whence is it that no air begins to be distilled, till the most volatile part of the oil begins to be separated from the wood? *Fraxinella* is a very odorous plant; when in full blossom, the air which surrounds it in a still night, may be inflamed by the approach of a lighted candle: Does this inflammability proceed from an inflammable air, which is exhaled by the plant, or from some of the finer particles of the *oil* of the plant, being *dissolved* in the common air of the atmosphere? Whence is it that the oils distilled
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from wood, during the same operation, are of different colours, consistencies, and specific gravities? Does this variety depend upon the loss of the air, or upon the quantity of the acid mixed with the oils? Are the oils and acids of different woods distinguishable from one another, by any specific differences, or do they only differ from one another as to more or less? Supposing the acids obtained from different woods to be of the same sort, and to be purified to the greatest degree, what kind of salts would they form, when united with alkalies, earths, and metallic substances? In what manner are the relative proportions of the water, acid, oils, air and residuum separable from wood by distillation, influenced

by the operation being conducted with a quick or a slow fire?

These, and a great many similar questions, might be resolved with the greatest accuracy, and our knowledge be thereby much advanced. But it falls to the lot of few to be able to build commodious Elaboratories, to purchase suitable instruments, to supply proper materials, and to maintain operators to execute the infinite variety of experiments which might be devised, for the regular and systematic improvement of every branch of Chemistry.

The residue remaining in the retort, after the distillation of the wood, is a perfect charcoal, and that which remains after the distillation of pit-coal, is a light spongy mass, in appearance,

pearance, and, indeed, in quality, resembling a substance prepared from pit-coal, as an article of trade, and which is usually called *coak* or *cinder*.

At *Newcastle* 24 barrows of coals produced generally but 18 barrows of cinders, and the price of a bushel, or of any other measure of cinders, is commonly one third more than the price of the same measure of coals *. At *Cambridge*, on the contrary, where great quantities of cinders are prepared for the drying of malt in the town and neighbouring villages, the price of cinders and of coals is the same. From this circumstance it might probably be inferred, that the coal was increased in bulk by being converted into cinder, otherwise the Merchant would have no compensa-

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* Voy. Metal. par M. Jars. p. 211.

tion for the expence attending the process. Upon examining the fact, I found that in one instance 30 bushels of coal gave 39 bushels of cinders, and in another 28 bushels of coal gave 36 bushels of cinders. The quantity of cinders, being estimated by *measure*, depends much upon the cinders being in rounder lumps than the coals; and the real quantity, estimated by *weight*, depends greatly upon the degree of heat to which the cinder has been exposed. I take the difference in the bulks of the Newcastle and Cambridge cinder, procurable from an equal quantity of coals, to proceed from the different degrees of heat to which they are exposed; the Cambridge coak ovens being drawn once in 24 hours, and those

those at Newcastle only once in 48 hours, or thereabouts.

In order to see what effect a longer continuation of fire would have upon the ordinary Cambridge cinder, I took a large piece, and having broken it, threw one part of it into the middle of a fierce cinder fire, employed in the drying of malt. This part became red hot in less than ten minutes; after it had continued in that situation for above two hours, I took it out, and when it was cold I found it considerably wasted in bulk, but it appeared to be harder and blacker than the other part of the same piece, and its parts were certainly more condensed; for I found that a cubic foot of the ordinary cinder weighed 1090 ounces, and a cubic foot of that which had been exposed

to the fire for two hours, weighed 1208 ounces. This cinder was, probably, as much changed in the space of two hours, by the strong draught of the fire in which it was put, as it would have been by a much longer continuance in the coak oven, where the draught of air is very little : and from this experiment it may be inferred, that the quantity of cinders procurable from a definite quantity of coals, depends very much upon the strength and continuance of the fire, since the cinder, after it is fully formed, is not only wasted in part by a longer continuance in the oven, but the part which remains is rendered more dense, and upon both accounts the quantity, estimated by measure, is lessened. This observation may be of use to those who are employed in
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preparing cinder for sale; and upon inquiry I find, that the quantity of cinder procured from the same quantity of coal is very variable : when the operation has been longer, or the heat greater than usual, instead of gaining of six or eight bushels from every thirty bushels of coal, they sometimes are not able to get even 30 bushels of cinder.

The consumption of charcoal in fluxing iron from its ores, and in manufacturing it into bar iron, is so very considerable, and the price of charcoal, from the great scarcity of under-wood in this kingdom, is so great, that many attempts have been made to substitute in this business charred pit-coal in the room of charcoal. These attempts have in part succeeded, and iron is now very

generally extracted from its ore by fires made with coak. But the iron thus procured is very fragile and coarse, and cannot, without great difficulty, be rendered as malleable as that which is fluxed with charcoal; it may answer nearly as well for casting, but it cannot be made into good bar iron by any art hitherto known. Hence it became an object worthy the contemplation of the society for the encouragement of arts, manufactures, and commerce, to propose premiums for the making of pig iron, and converting pig iron into bar iron with coak. The pigs and bars were required to be as good as those made with charcoal, but the premiums, though proposed from 1762 to 1766 were never claimed*.

Those

* Memoirs of Agriculture, Vol. I. p. 220

Those who are interested in iron works, have motives, more prevalent than the society's premiums, to induce them to perfect the art of smelting by means of charred pit-coal; and it may not be an useless hint to them, to try the effect of coak, which has undergone different degrees of heat. I ordered a ton of coals to be put into a coak oven, and when it was in the usual way converted into a cinder, I found that it weighed 11 hundred weight; had it stayed longer in the oven it would have been reduced further, and it may deserve to be inquired, whether there is not a definite weight to which any given quantity of coals ought to be reduced, in order to produce the best possible coak for the fluxing of iron

iron ore. The * *Alais* pit-coal is said to lose half of its weight by being reduced to coak, whilst another sort of coal lost only 35 parts in an hundred: this diversity may depend partly on the nature of the coal, but principally, I conceive, on the degree and continuance of the fire used in the preparation of the coak.

“ What shall I say further of coals, except I tell you of one *Becher*, in King Charles the Second's time, who pretended to make *pitch* and *tar* from them, but I think his project came to nothing†.” This is *Houghton's* observation concerning a project of one of the greatest chemists that ever lived. Whatever fate his project met with in his own age,

* Instruc. sur l'Usage de la Houille, p. 81.

† *Houghton's Collec.* Vol. II. No. 242.

age, it has been realized in ours; for a kind of tar has for several years last past been prepared from coal in the bishopric of *Liege*, and in other parts of Germany; we also make considerable quantities in England, especially near *Broseley*, and at *Bristol* *; a person at Bristol having obtained a patent for making tar from pit-coal, the condition of which, if I am rightly informed, is, that every person who undertakes to procure
tar

* In the *Philos. Transf.* No. 228, year 1697, there is mention made of pitch and tar being then separated at *Broseley*, in *Shropshire*, from the black bituminous stone which lies over the coal. It was separated, partly by boiling the stone, and partly by distilling it—the present method of obtaining pitch from pit-coal is a great improvement upon the former practice.

tar from pit-coal must pay a shilling a barrel to the patentee.

The method of making *tar* is thus described by Newmann.—“ Tar is prepared in different parts of Germany, Norway, Sweden, &c. from the pine and the fir-trees, and in some places from the larch and the terebinth. The wood is inclosed in a large oven to the quantity of ten or more loads at a time : this stands within another oven called the mantle, the space between them receiving the fire. From the bottom of the inner oven runs a gutter, by which the tar is conveyed off in proportion as it melts out of the wood *.” This process is a kind of distillation, in which the inner oven repre-

* Newmann's Chem. p. 288.

represents the body of the retort, and the gutter its neck. The fluid parts of resinous woods are probably capable of being melted out of them with a less degree of heat than what is requisite for the distillation of coal, yet the process for procuring tar, here mentioned, might be applied, with a few alterations, to the obtaining the thick oil of coals.—There would in this plan be no loss of fuel, the coal contained in the inner oven would be converted into one of the most valuable kinds of coak, and the fire between the ovens would afford a cinder as good as the common cinder.

In the bishopric of *Liege* the coal is distilled in a kind of still composed of two large cast-iron pots. In England the coal is put into ovens
which

which are heated by fires lighted under their bottoms, and the liquid matter is forced through an iron pipe inserted into the top of the oven, and which communicates with proper condensing vessels. As the pitchy oil is very heavy, the distillation, I think, would be most advantageously performed by making the fire on the top of the oven containing the coal, so that the liquid matter might be made to descend through a pipe inserted into the bottom of the oven, and communicating with proper receivers.

In the great works they obtain the very same substances which we got from the analysis of coal—a corrosive watery liquor, and two sorts of oil. The two oils are put into an iron still, in order to their
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being further purified from the watery liquor with which they are mixed; 6 barrels of this oily matter produce about 5 barrels of oil of a thicker consistence; of the oil thus thickened one part is lighter than the other, the lighter part is drawn off from the other, and is not at present applied to any use; the thicker part is used as *tar*, for the paying the sides and bottoms of ships, but it is not found to answer so well as tar, either for cordage, or to mix with oakum.

Those who are interested in the preparation of coak would do well to remember, that every 96 ounces of coal would furnish 4 ounces at the least of oil, probably 6 ounces might be obtained; but if we put
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the product so low as 5 ounces from 100, and suppose a coak oven to work off only 100 tons of coal in a year, there would be a saving of 5 tons of oil, which would yield above 4 tons of tar: the requisite alteration in the structure of the coak ovens, so as to make them a kind of distilling vessels, might be made at a very trifling expence.

It has been before observed, that wood and pit-coal wholly resemble each other in the products which they yield by distillation, and as the oil from pit-coal is found to answer the purpose of tar, it might surely be a matter worthy the consideration of those who are engaged in the burning of wood into *charcoal*, to contrive means which might easily be

be done, of saving all the oil which is separated from the wood during that operation.

The acid liquor which is procured from pit-coal, when it is distilled for tar, is at present thrown away, as I have been informed by a person who is much engaged in this business. Without entering into the dispute concerning the origin of the vegetable fixed alkali, we may observe, that it is generally obtained from the combustion of the vegetable, and there is reason to think, that the *acid* of the vegetable contributes in some way or other towards its production : thus the concrete acid of tartar yields, by being burned, a great quantity of fixed alkali. Is it wholly improbable, that the *acid* liquor which is separated from the coal by distillation,

might be converted into a *fixed alkali* by being boiled down and calcined, either by itself, or in conjunction with straw, charcoal dust, or any other substance, containing the inflammable principle?

The making of fixed alkali in Great Britain, is a matter of such great national concern, that the commercial reader will excuse me, if I give another hint or two upon the subject. Might not pot-ash be prepared in the cyder countries, from the calcination of the *acid* earthy pulp, which remains after the juice is pressed out from the apple? The brewery *grains* are at present applied to some use, would they not, if suffered to turn *sour*, yield more profit by being calcined for pot-ash? The brewery hops, which are impregnated

with the sweet wort, would probably turn sour, and as they are thrown away as useless, might it not be advisable to see whether they would not yield pot-ash by calcination? The lees and refuse from the making of vinegar, might be tried for the same purpose; and so might all the water which is impregnated with the washings of the floors, vessels, &c. in which any vegetable liquor is fermented, either into ale or vinegar. I remember having evaporated, several years ago, a large quantity of horse's urine, with a view of seeing whether it would yield by crystallization, the same kind of *phosphoric* salt, which may be obtained from human urine; I could not procure any salt of that kind from it; but when it was evaporated to dryness,

it yielded, even without *calcination*, a great deal of *fixed alkali*. The urine of animals, which feed upon vegetables, arises from the juices of the vegetables, which have been changed in some degree by the organs of digestion; may not a similar change take place by putrefaction? and may not the putrefaction of vegetable juices be increased, by a small admixture of common salt? and would not the quantity of alkali be thereby increased? Is it not possible to *decompose* common salt, by mixing it with vegetables in a state of putrefaction? If the acid of salt could by any cheap means be separated from its alkaline basis, it would undoubtedly be the interest of government to exempt from the salt duty, all such rock or sea salt, as should be converted

verted into a fixed alkali; for by that means, all the money might be kept in the kingdom, which is now sent out of it, for the purchase of barilla, and other sorts of fixed alkali.

It has, with some men, been a subject of apprehension, lest all the coal-pits in England should soon become exhausted. The quantity of coal which is annually raised, is certainly very great; and as coal is not found to grow again, the time must come, when it will all be consumed. That æra, however, is certainly at a great distance, since in those countries where coal is found, they are constantly opening fresh pits, and may for centuries to come continue to open more; and coal may, probably, be discovered in many countries, where none is extracted at pre-

sent. It will enable the reader to form some notion of the great excavations, which are annually made in this island from the digging of coal, if we calculate the extent of that which is made in one year, in consequence of the coal which is imported into London. The following account may be relied on :

An account of coals imported into the port of London, in ten years, ending at Christmas, 1779.

Christmas	1770	- -	615,330 chalders.
	1771	- -	694,003
	1772	- -	725,008
	1773	- -	624,781
	1774	- -	623,727
	1775	- -	672,786
	1776	- -	700,207
	1777	- -	697,435
	1778	- -	647,361
	1779	- -	587,895
Annual average			<hr/> 658,853

No accounts are kept at the Custom House, distinguishing the importation from Newcastle, Sunderland, Blythe, Hartlepool, &c. or from the several parts in Scotland and Wales, the Crown revenue not being affected thereby. The duty is 8 s. per chalder of 36 Winchester bushels, on all coals sold by measure, and 6 s. 4 d. per ton, on such as are sold by weight. It appears from the preceding account, that in the year 1777, there were imported into the port of London 697,435 chalders, and we learn from another authority *, that in the same year there were imported from *Newcastle* and *Sunderland* alone 692,093³/₄ chalders; by comparing these numbers, we may observe how small a portion of

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the

* Ann. Reg. 1777, Ch. 161.

the coal consumed in London, is brought from any other quarter.

A chalder of coals, Newcastle measure, is allowed by Act of Parliament * to weigh 53 hundred weight : and as 8 Newcastle chalders are equal to 15 London chalders, reckoning 36 Winchester bushels to the London chalder, it follows, that a chalder of coals, London measure, is equal to a little more than 28 hundred weight. But supposing 28 hundred weight to be the weight of a London chalder, then as the medium quantity of coal annually imported into London is 658,853 chalders, it may be collected, that there are annually imported 922,394 tons.

The following table expresses the relative

* 6 & 7 W. & M. III. c. 10. s. 2.

relative weights of a few different
sorts of coals.

Weight of a cubic foot of

Welsh coal - - -	1396	ounces avoird.
Yorkshire stone-coal	1307	—
Lancash. cannel-coal	1273	—
Newcastle upon Tyne	1271	—
* Staffordshire coal	1241	—
† Coal de Graiffesac	1371	—
† Coal des Carmaux	1333	—
† Coal d'Alais - -	1500	—
Medium weight	<u>1336</u>	ounces avoird.

The Welsh coal was of that kind
which burns without giving any
smoke, they mix it here with cinder
for the drying of malt. The York-
shire stone-coal was taken from a pit
near

* Philos. Transf. No. 169.

† The weights of the three French coals
were calculated from experiments mentioned
in Instruct. sur l'Usage de Houille, p. 2.

near Wakefield, and is part of the stratum, which lies at the bottom of the black coal. The Cannel coal was from Wigan in Lancashire: this coal is commonly used by the country people to work by in winter nights, instead of candles, and its name has been probably derived from its use, candles being called in the dialect of the northern counties, cannels.

The Newcastle coal was of a kind which is much esteemed at Cambridge, and which is called *Old Ducks*. The medium weight of a cubic foot of these several coals being 1336 avoirdupois ounces, a cubic yard or 27 cubic feet of coal, will weigh $2254\frac{1}{2}$ avoirdupois pounds; there are 2240 such pounds in a ton, hence we may say in general, that a cubic yard
of

of pit-coal weighs a ton ; some sorts of coal weigh a few pounds more, and other, a few pounds less than a ton. From what has been before observed concerning the quantity of coal annually imported into London, we may now conclude that 922,394 cubic yards of coal are annually dug out of the earth for the supply of the London market. This quantity of coal, if spread to the thickness of an inch, would cover an area of above 10 square miles ; and no doubt the consumption of so large a quantity contributes very much both to the daily dirtiness of the streets of London, and to that elevation of soil which is sufficiently obvious in the city and its environs, when distant periods of time are compared together.

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The weight of a London chalder of coals is here put equal to 28 hundred weight, upon the supposition of 8 Newcastle chalders being equal to 15 London chalders. Upon weighing a bushel of the middle sized, large, and small *old ducks*, at Cambridge, I found the weights to be

Middle sized	-	74
Large coal	-	76
Small coal	-	80
		<hr/>
Medium	-	76 $\frac{2}{3}$
		<hr/>

This médium does not give quite 25 hundred weight to a chalder. I found, by weighing coals at another warehouse in Cambridge, that 30 bushels made a ton, which is $74\frac{2}{3}$ pounds to a bushel.

It is not certainly known how long coal has been dug in Great Britain;

Britain ; the first sort of fuel which all nations used was probably wood, and as that grew scarce men began to search into the bowels of the earth for something to supply its place. We have good reason to believe that the Newcastle coal pits were wrought in the time of the Romans, for coal cinders have been found at the bottom of the foundation of a city built by the Romans in that county * ; but whether they were not wrought by the Britons before the Roman invasion, is a question which cannot, perhaps, be positively decided either way.

Anderson, in his History of Commerce, fixes the introduction of Newcastle coal into London at so early a period as the year 1305 ; and
mentions

* Wallis's Hist. of Northumberland.

mentions a complaint of the nobility and gentry, which was preferred to the King against the use of sea-coal, as a public nuisance. A similar prejudice prevails at this day, among those who have not been accustomed to pit-coal fires. The great Hoffman had given it as his opinion, that the peripneumony, the dry asthma, and the consumption were common maladies amongst the inhabitants of Liege and London, and that they were occasioned by the great use of pit-coal in those places. M. Morand, in 1769, was at the trouble to inquire into this matter, and it appears from the attestations of the College of Physicians in *London*; of the Faculty of Medicine at *Paris*; of the physicians at *Liege*, at *Lyons*, and other places, that

that the opinion concerning the peculiar insalubrity of pit-coal fires is utterly without foundation.

It has been remarked that coal, in being distilled, yields near $\frac{1}{3}$ of its weight of air; in being consumed by burning, it yields a great deal more; for both the residue remaining in the retort, and the oil obtained by distillation, yield much air during combustion. I do not think that it would be an extravagant supposition, if we should say, that the 922,394 tons of coal which are annually consumed, dispersed into the atmosphere incumbent over London, 500000 tons of air; and this quantity may, probably, be about $\frac{1}{4}$ of the whole quantity of air, which is respired by the inhabitants of London in the course of a year.

Hence,

Hence, though it should be granted that the air from coal is not more unwholesome than that which is separated from any other kind of fuel, yet the vast quantity of it with which the common air over great cities is daily infected, may contribute something to the rendering them, what they have been justly called, the GRAVES of mankind.

END OF VOL. II.



